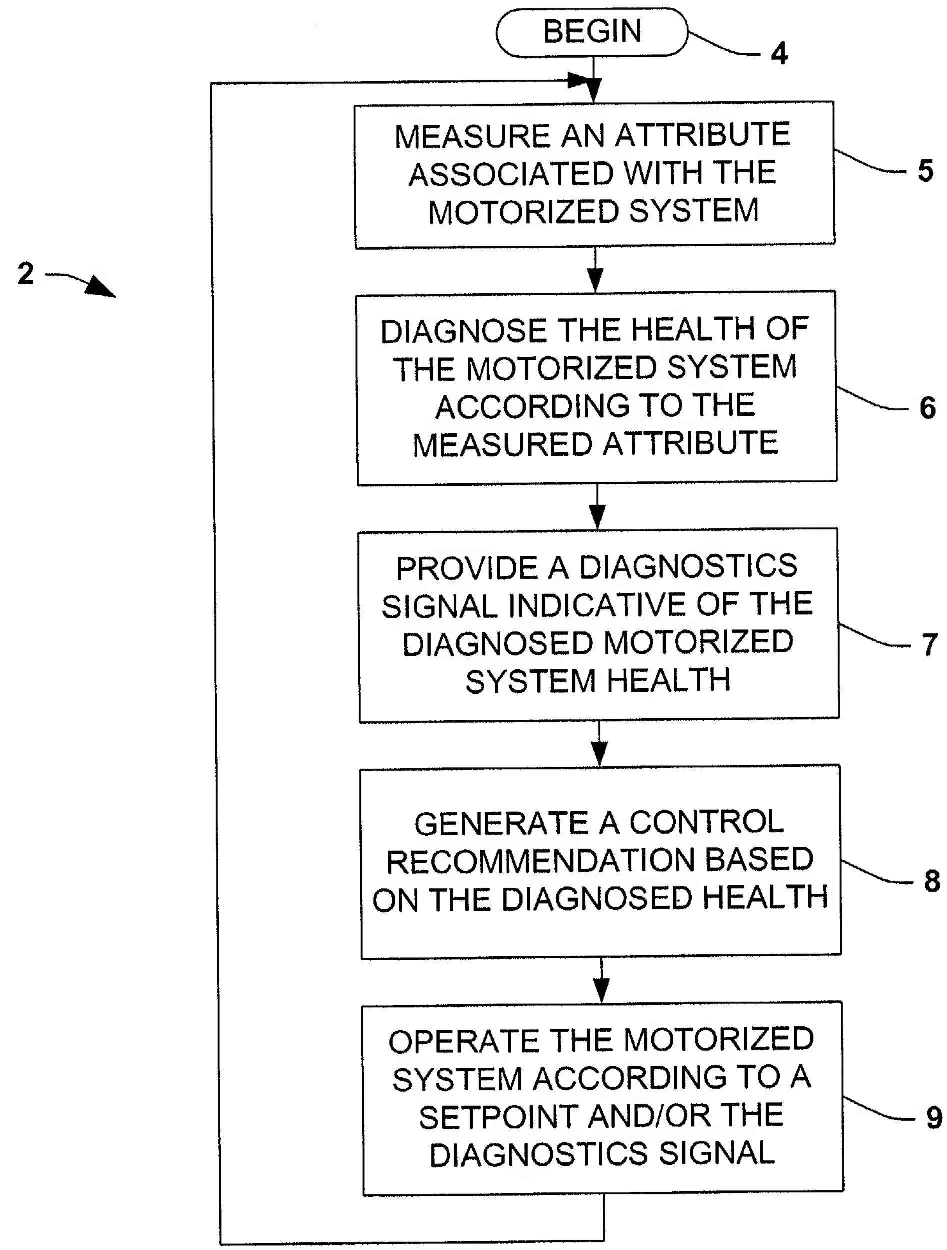
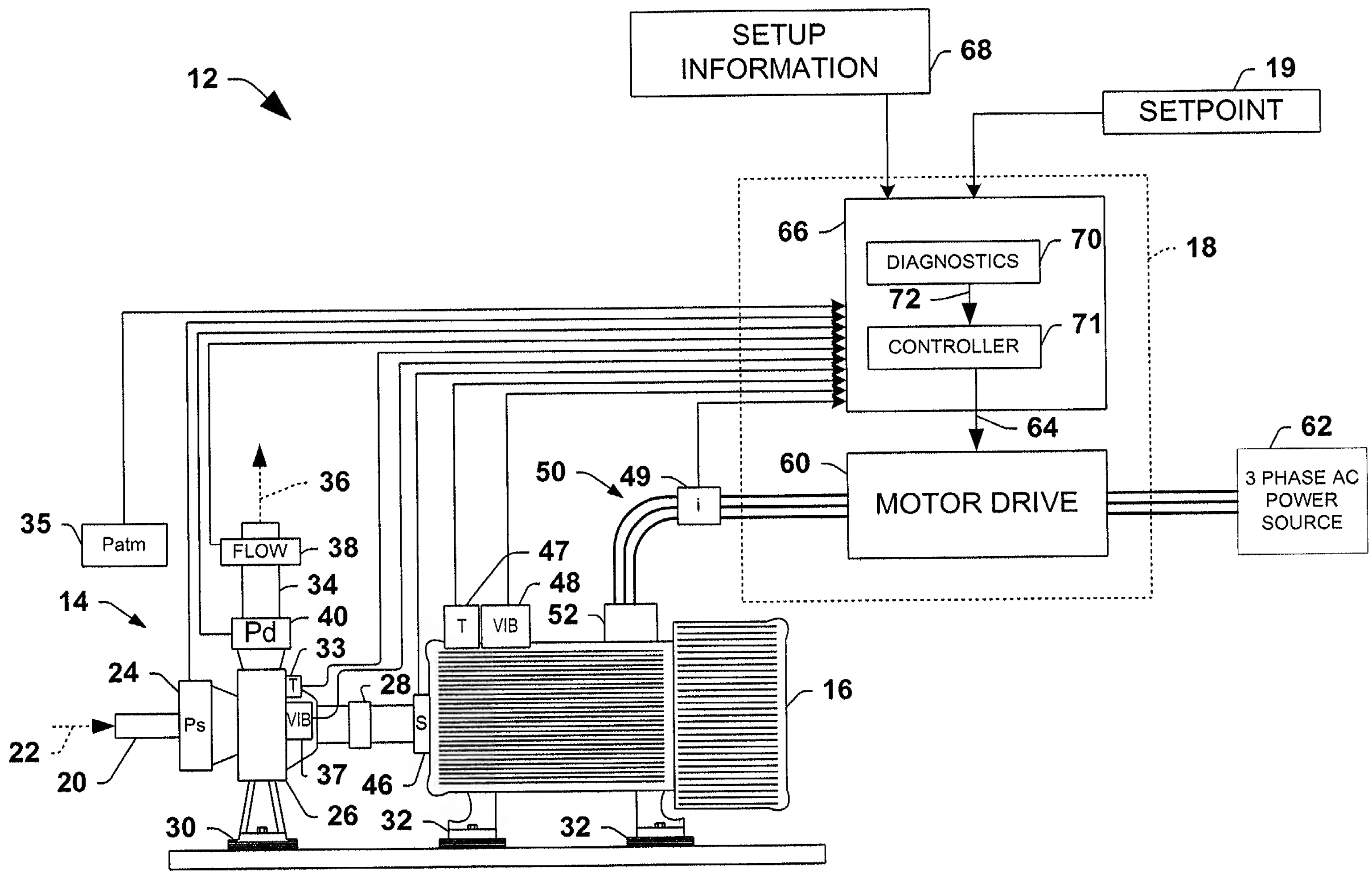

BEGIN
4
MEASURE AN ATTRIBUTE ASSOCIATED WITH THE MOTORIZED SYSTEM
5
DIAGNOSE THE HEALTH OF THE MOTORIZED SYSTEM ACCORDING TO THE MEASURED ATTRIBUTE
6
PROVIDE A DIAGNOSTICS SIGNAL INDICATIVE OF THE DIAGNOSED MOTORIZED SYSTEM HEALTH
7
GENERATE A CONTROL RECOMMENDATION BASED ON THE DIAGNOSED HEALTH
8
OPERATE THE MOTORIZED SYSTEM ACCORDING TO A SETPOINT AND/OR THE DIAGNOSTICS SIGNAL
9
2

FIG. 1



SETUP INFORMATION
SETPOINT
DIAGNOSTICS
CONTROLLER
MOTOR DRIVE
3 PHASE AC POWER SOURCE
Patm
FLOW
Pd
Ps
T
VIB
S
i
12
14
16
18
19
20
22
24
26
28
30
32
33
34
35
36
37
38
40
46
47
48
49
50
52
60
62
64
66
68
70
71
72

FIG. 2a

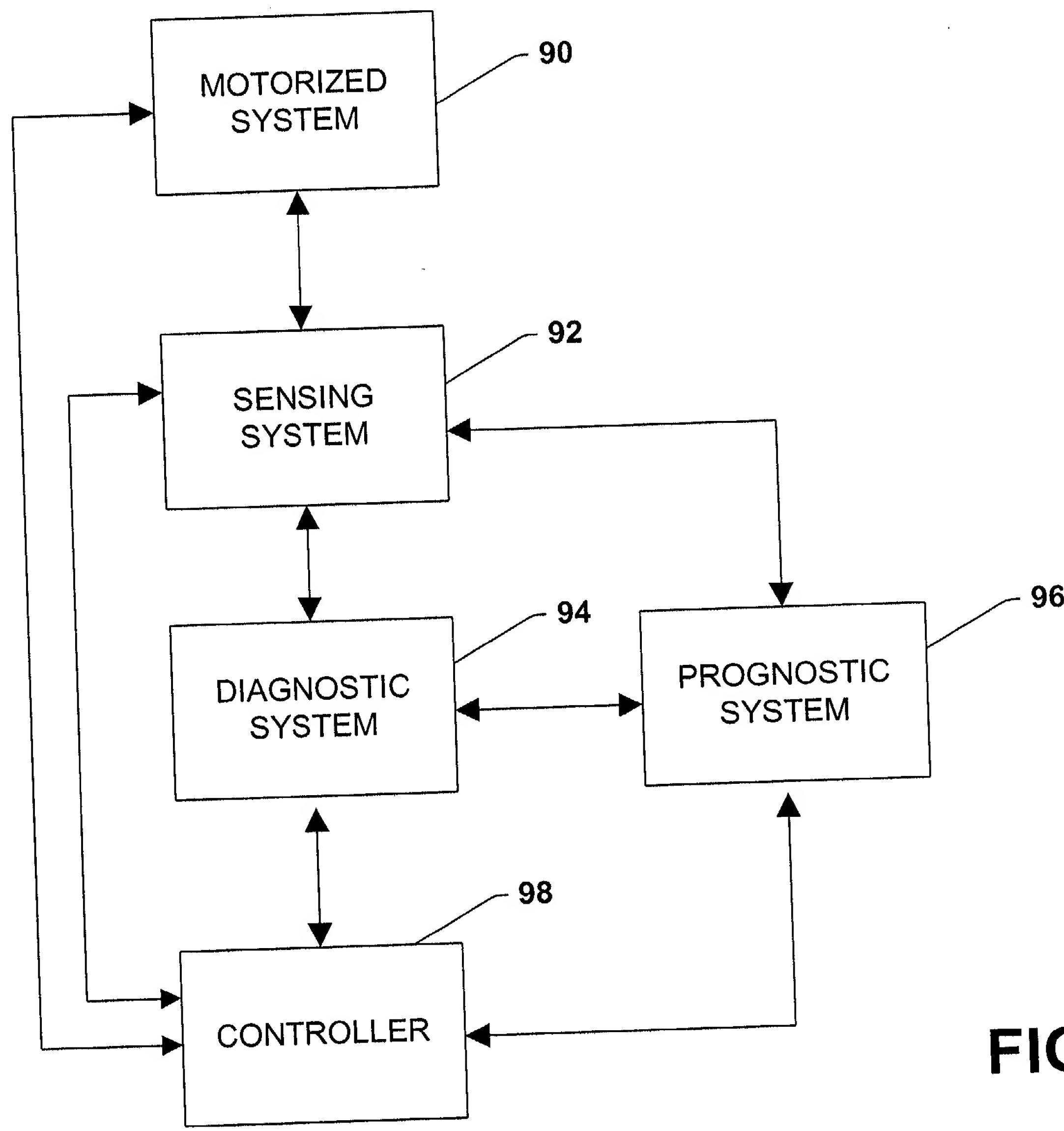
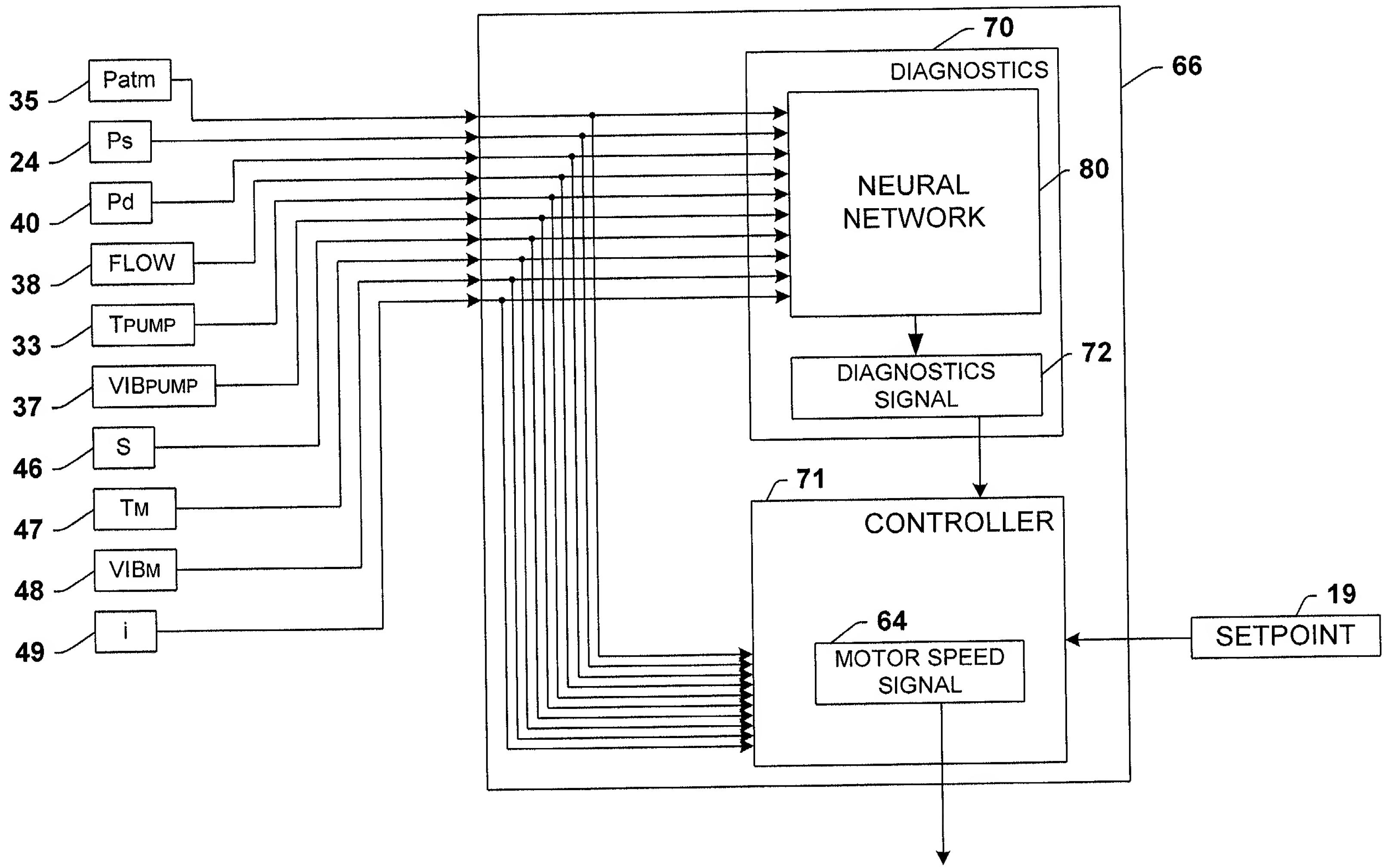

MOTORIZED SYSTEM
90
SENSING SYSTEM
92
DIAGNOSTIC SYSTEM
94
PROGNOSTIC SYSTEM
96
CONTROLLER
98

FIG. 2b



35
Patm
24
Ps
40
Pd
38
FLOW
33
TPUMP
37
VIBPUMP
46
S
47
TM
48
VIBM
49
i
66
70
DIAGNOSTICS
80
NEURAL NETWORK
72
DIAGNOSTICS SIGNAL
71
CONTROLLER
64
MOTOR SPEED SIGNAL
19
SETPOINT

FIG. 3

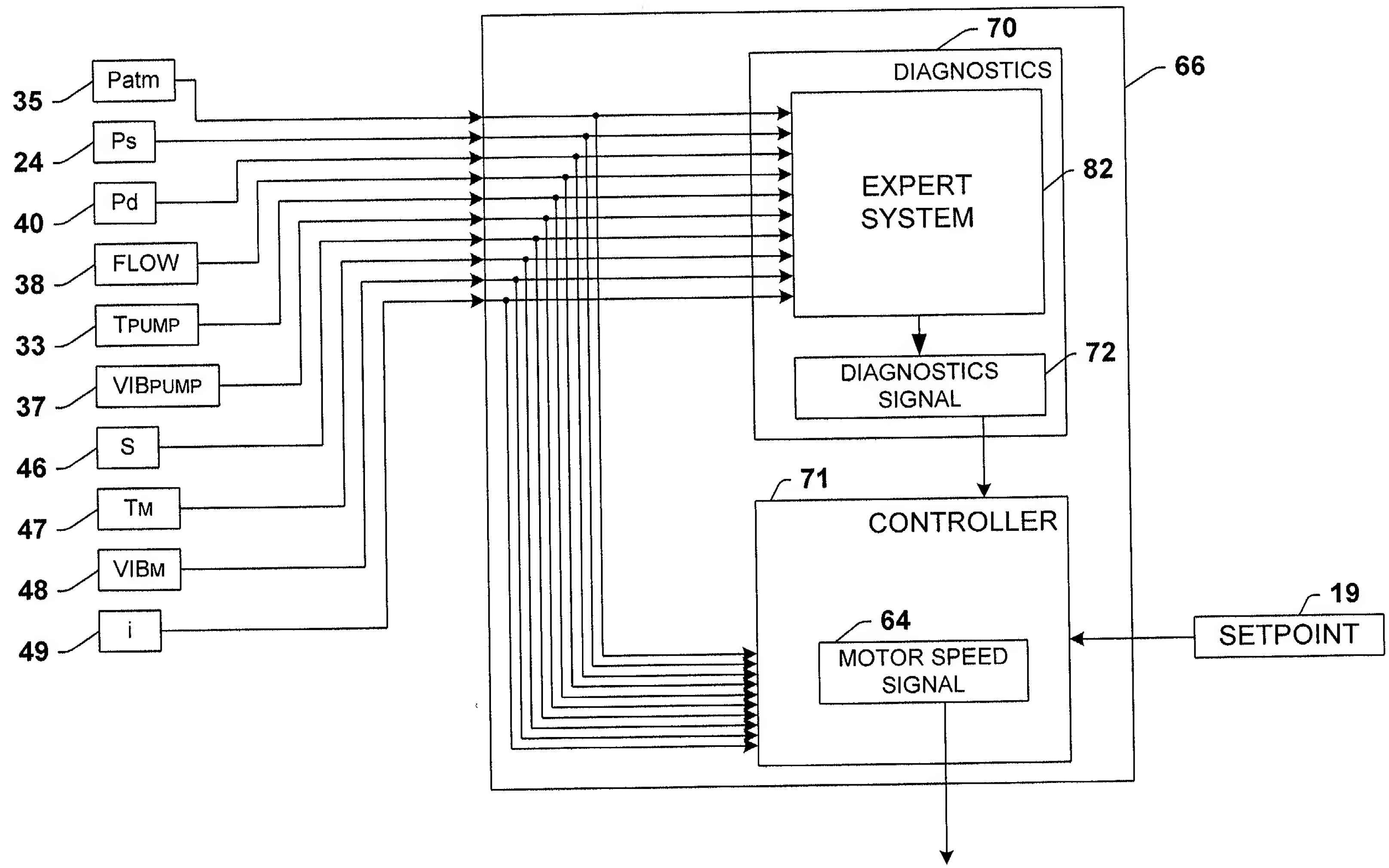

Patm
Ps
Pd
FLOW
TPUMP
VIBPUMP
S
TM
VIBM
i
35
24
40
38
33
37
46
47
48
49
66
70
DIAGNOSTICS
82
EXPERT SYSTEM
72
DIAGNOSTICS SIGNAL
71
CONTROLLER
64
MOTOR SPEED SIGNAL
19
SETPOINT

FIG. 4

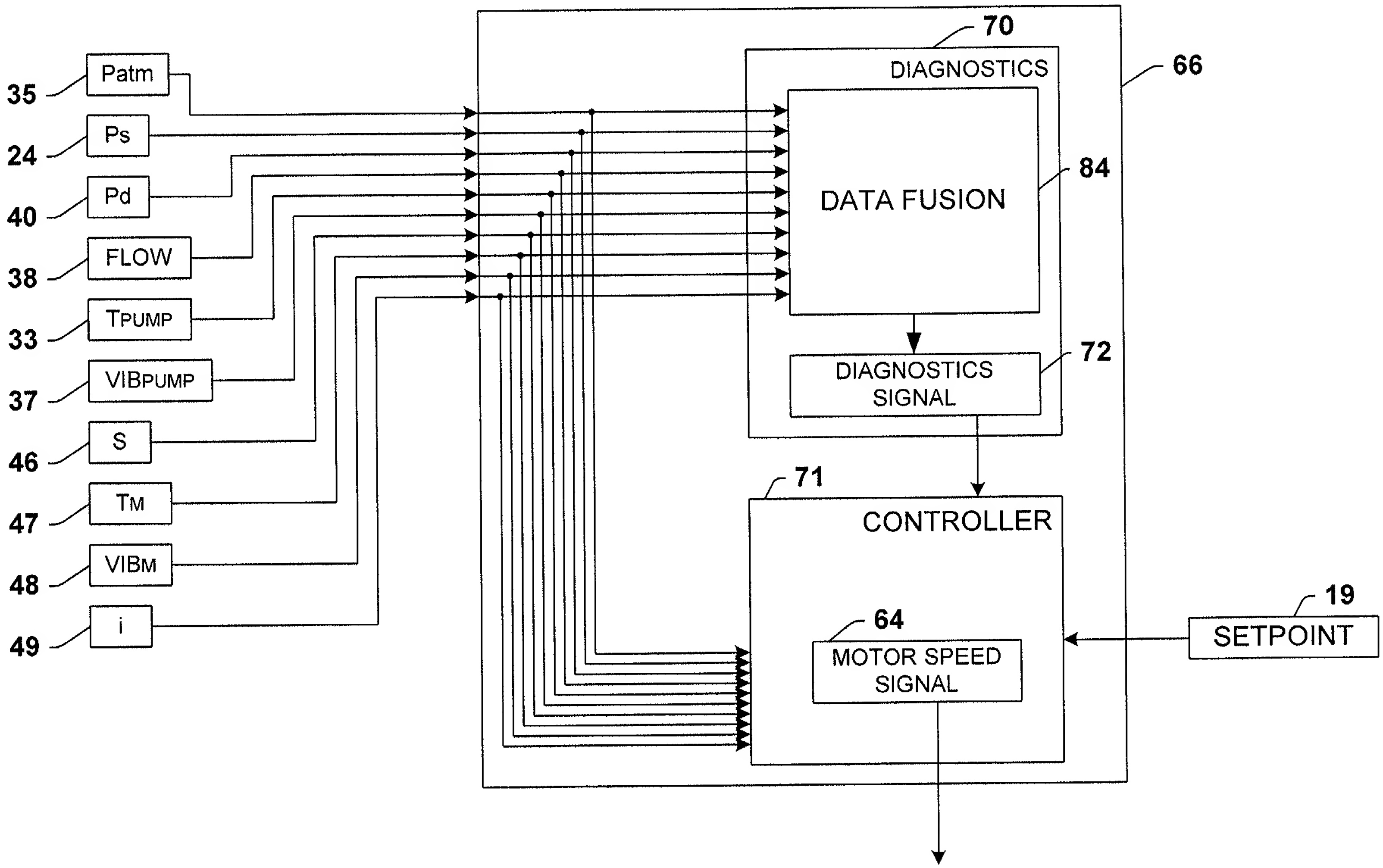

35
24
40
38
33
37
46
47
48
49
Patm
Ps
Pd
FLOW
TPUMP
VIBPUMP
S
TM
VIBM
i
66
70
DIAGNOSTICS
84
DATA FUSION
72
DIAGNOSTICS SIGNAL
71
CONTROLLER
64
MOTOR SPEED SIGNAL
19
SETPOINT

FIG. 5

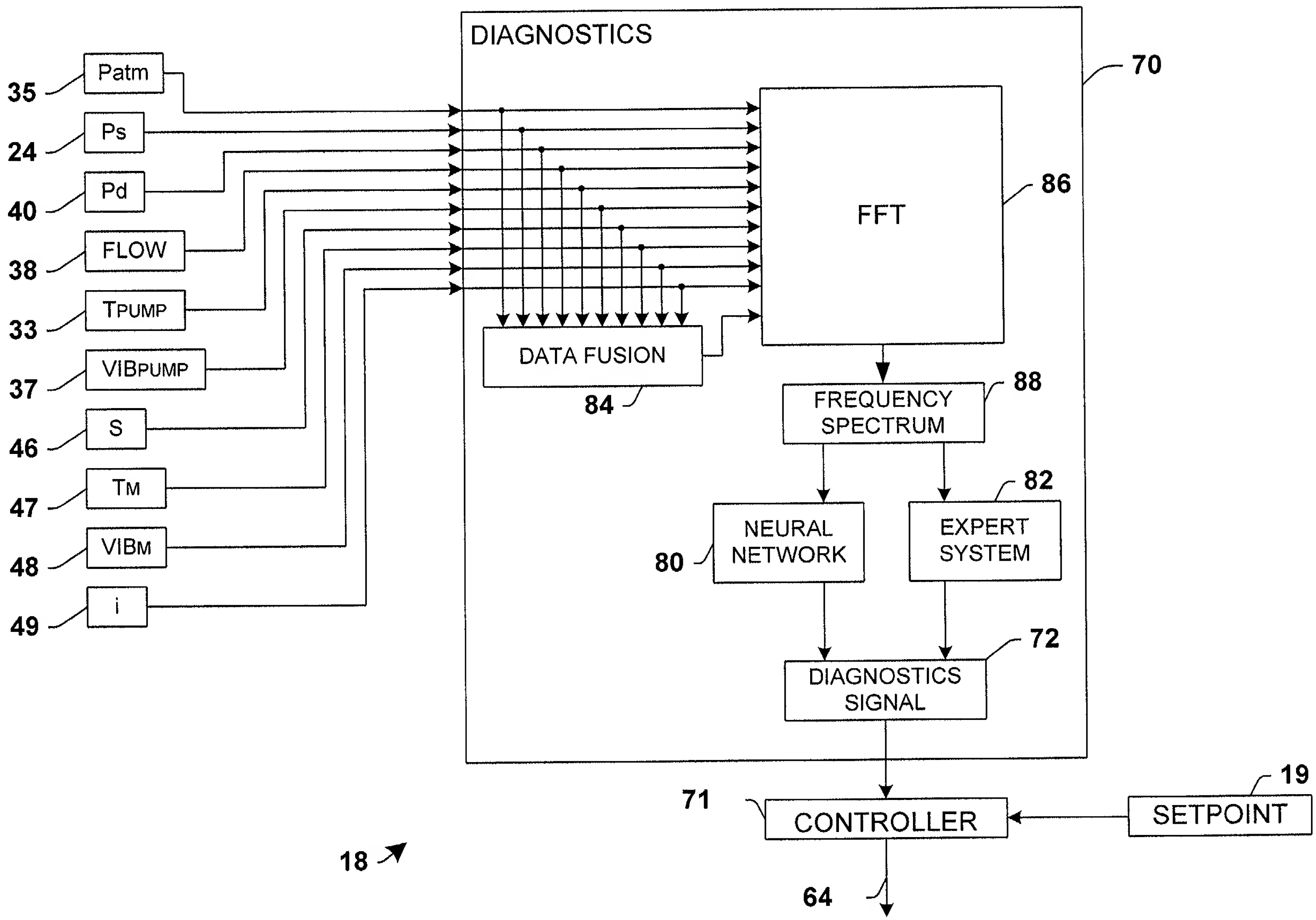

DIAGNOSTICS
70
Patm
Ps
Pd
FLOW
TPUMP
VIBPUMP
S
TM
VIBM
i
35
24
40
38
33
37
46
47
48
49
FFT
86
DATA FUSION
84
FREQUENCY SPECTRUM
88
NEURAL NETWORK
80
EXPERT SYSTEM
82
DIAGNOSTICS SIGNAL
72
CONTROLLER
71
SETPOINT
19
64
18

FIG. 6

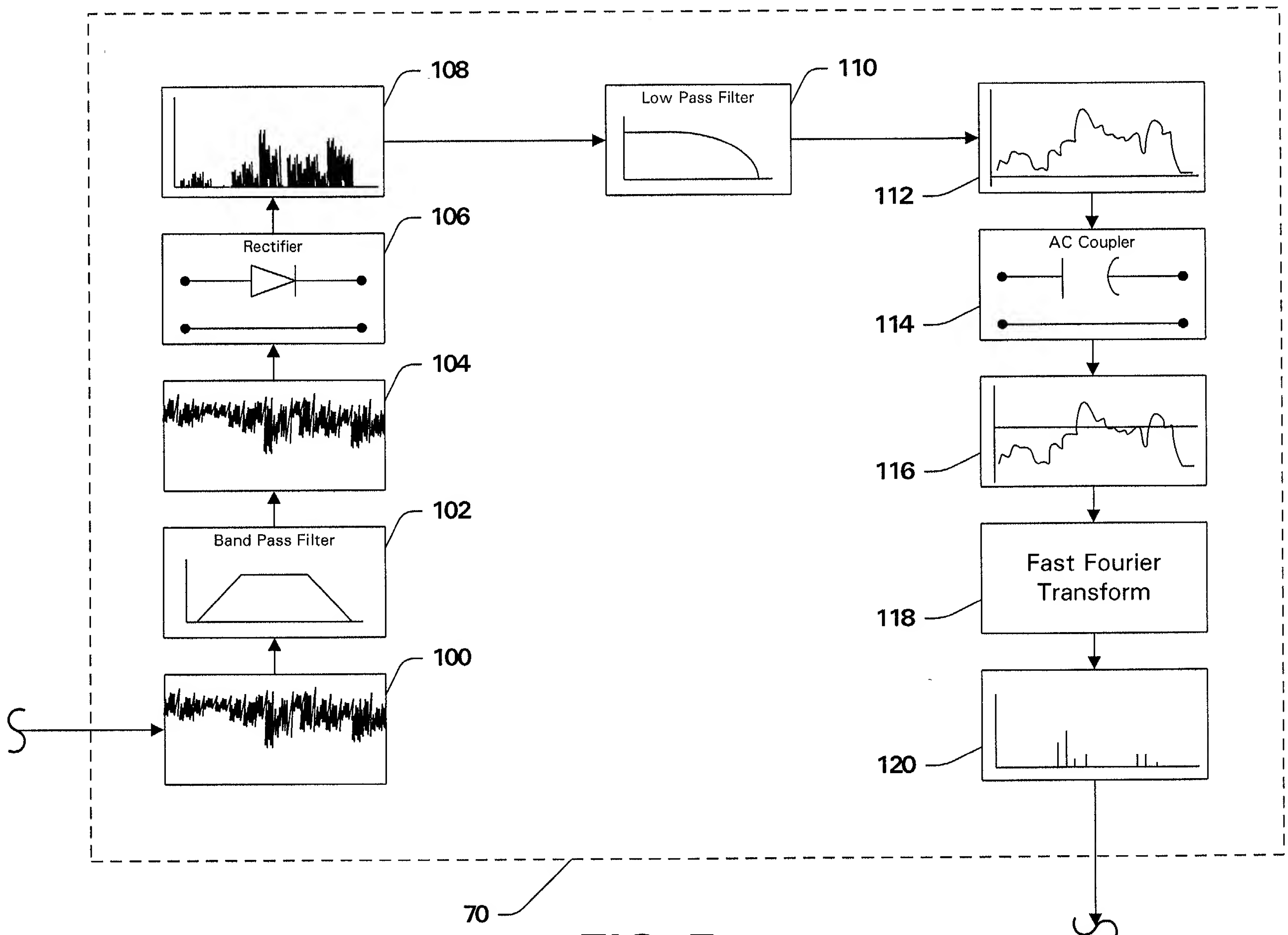

108
110
Low Pass Filter
106
Rectifier
112
104
114
AC Coupler
102
Band Pass Filter
116
100
118
Fast Fourier Transform
120
70

FIG. 7

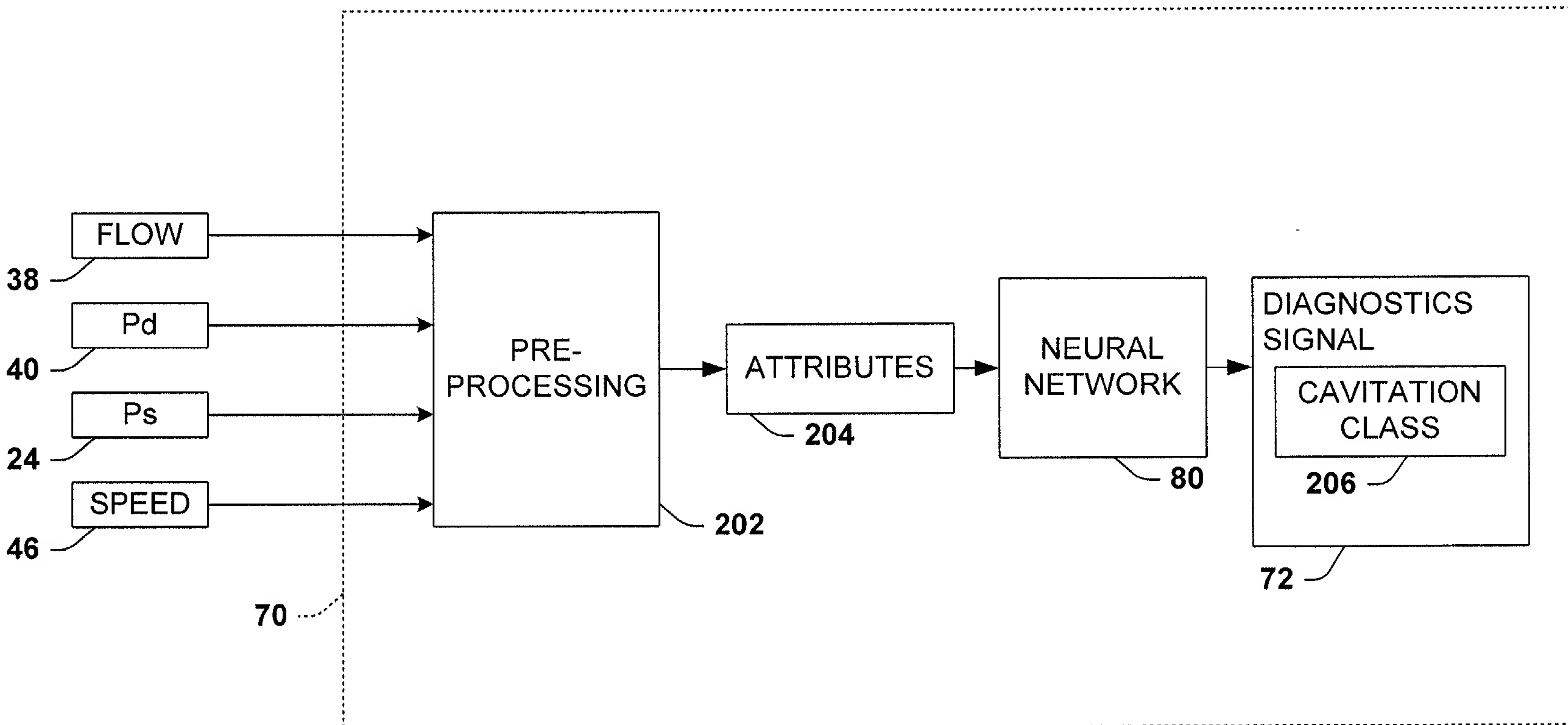

FLOW
38
Pd
40
Ps
24
SPEED
46
70
PRE-
PROCESSING
202
ATTRIBUTES
204
NEURAL
NETWORK
80
DIAGNOSTICS
SIGNAL
CAVITATION
CLASS
206
72

FIG. 8

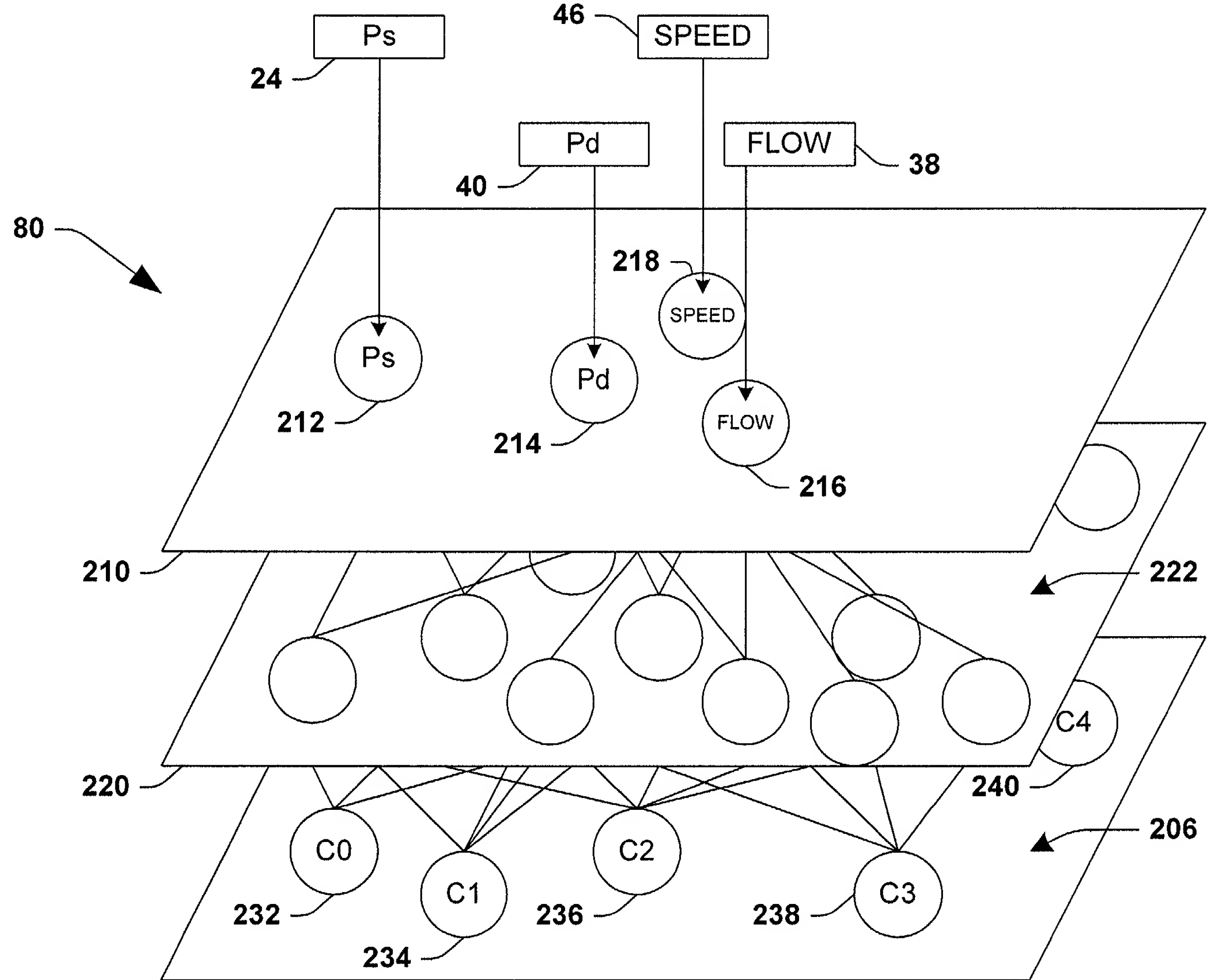
DIAGNOSTICS SIGNAL

206

CLASS 0	normal; no cavitation
CLASS 1	incipient cavitation; mainly balance hole cavitation
CLASS 2	medium cavitation; mainly vane cavitation
CLASS 3	full cavitation; large amount of bubbles on the suction eye but no surging
CLASS 4	surging cavitation; full blown cavitation with surging

72

FIG. 9



80
Ps
24
SPEED
46
Pd
40
FLOW
38
218
SPEED
Ps
212
Pd
214
FLOW
216
210
222
220
C4
240
206
C0
232
C1
234
C2
236
C3
238
230

FIG. 10

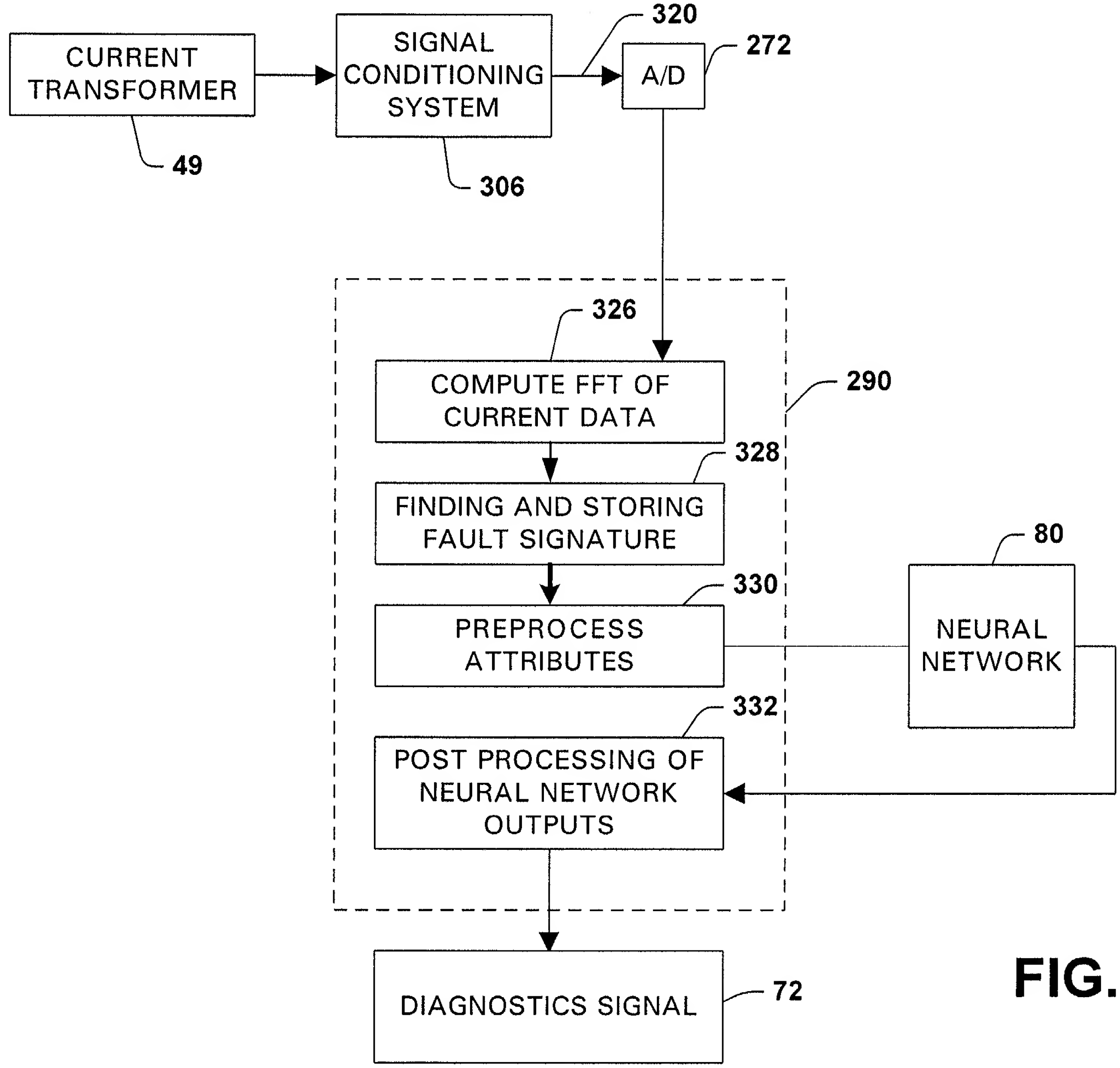

CURRENT TRANSFORMER
49
SIGNAL CONDITIONING SYSTEM
306
320
A/D
272
326
COMPUTE FFT OF CURRENT DATA
290
328
FINDING AND STORING FAULT SIGNATURE
330
PREPROCESS ATTRIBUTES
80
NEURAL NETWORK
332
POST PROCESSING OF NEURAL NETWORK OUTPUTS
DIAGNOSTICS SIGNAL
72

FIG. 11

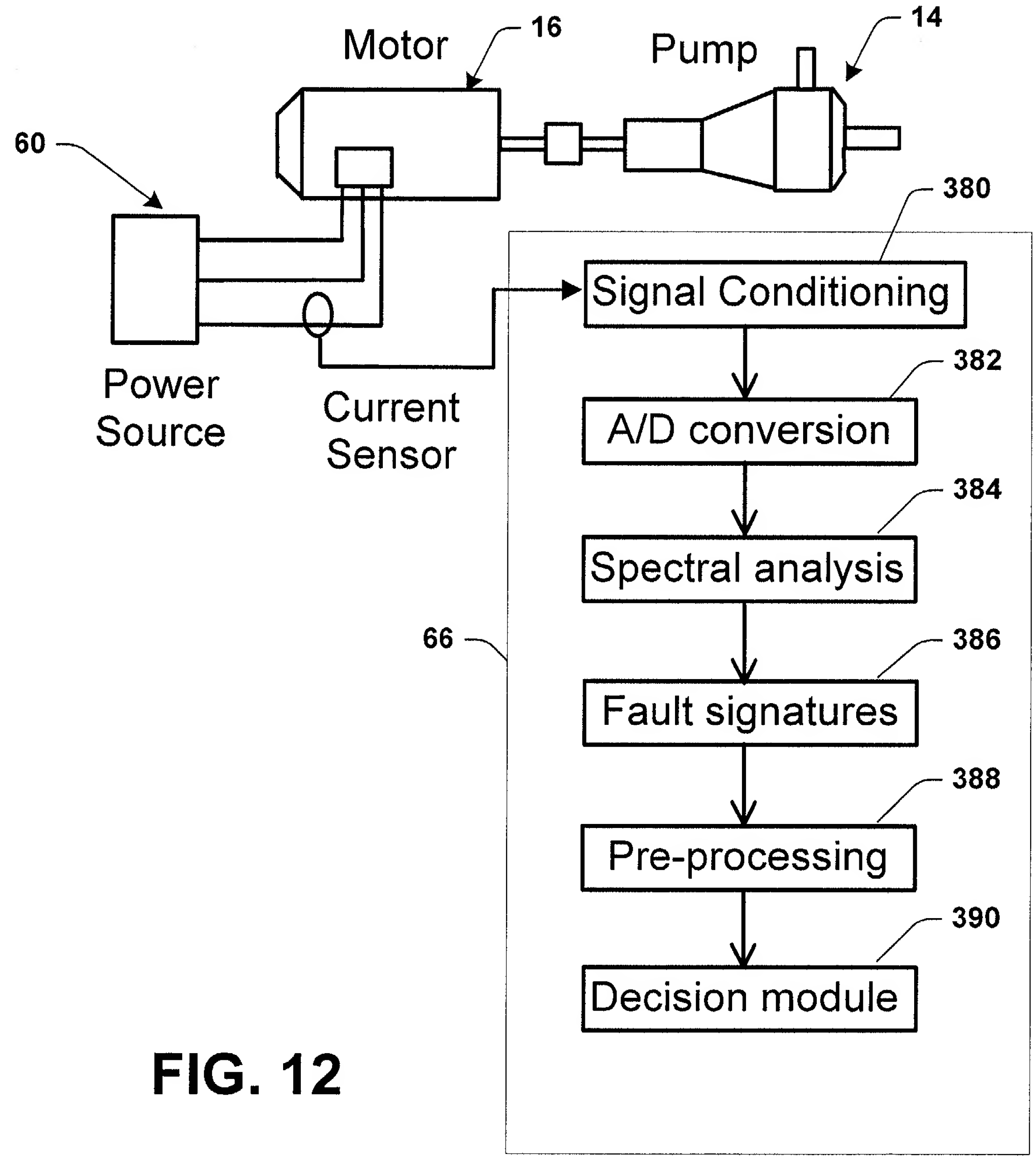
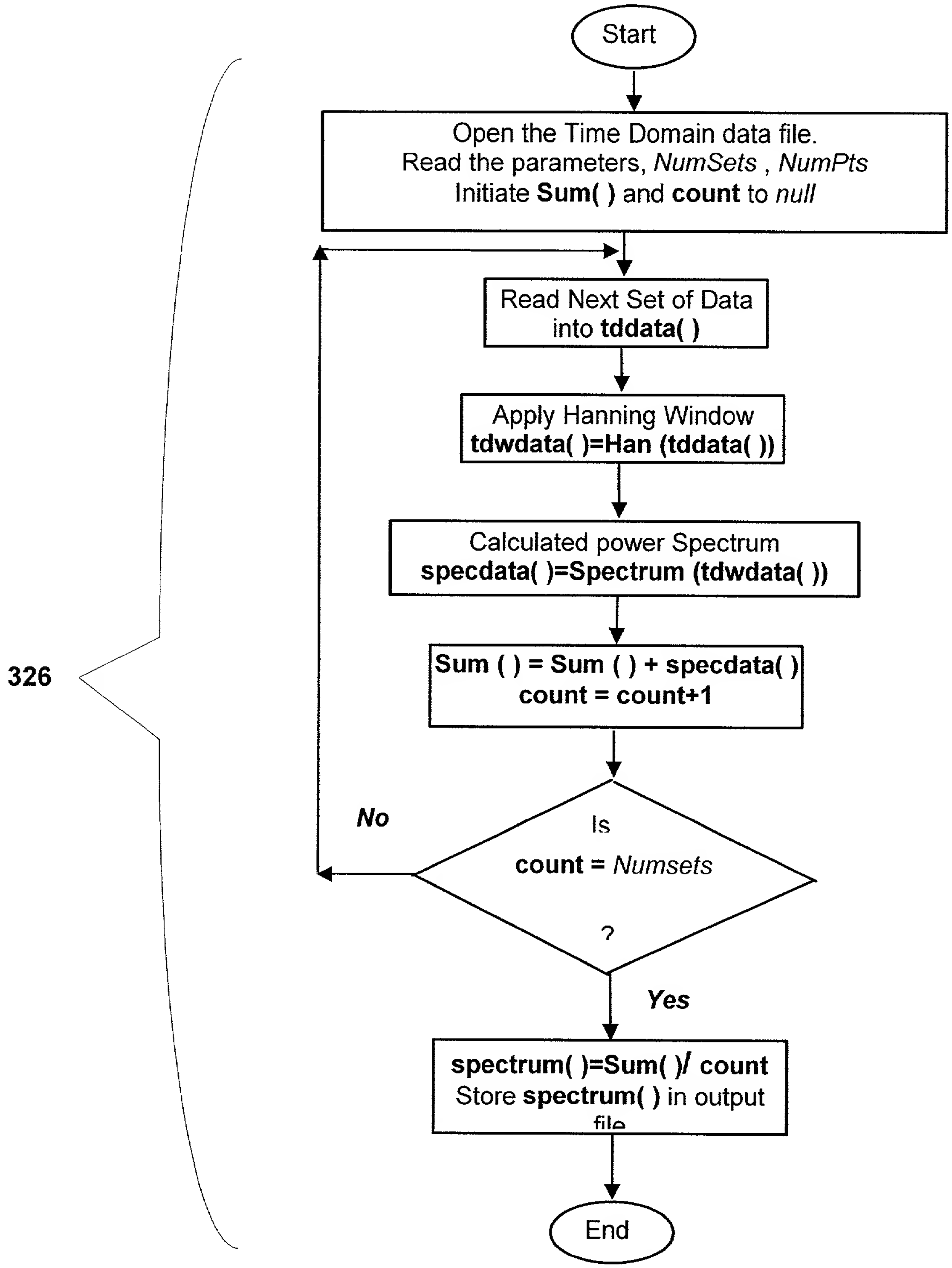

Motor
16
Pump
14
60
Power
Source
Current
Sensor
380
Signal Conditioning
382
A/D conversion
384
Spectral analysis
66
386
Fault signatures
388
Pre-processing
390
Decision module

FIG. 12



Start
Open the Time Domain data file.
Read the parameters, NumSets , NumPts
Initiate Sum( ) and count to null
Read Next Set of Data
into tddata( )
Apply Hanning Window
tdwdata( )=Han (tddata( ))
Calculated power Spectrum
specdata( )=Spectrum (tdwdata( ))
Sum ( ) = Sum ( ) + specdata( )
count = count+1
326
No
Is
count = Numsets
?
Yes
spectrum( )=Sum( )/ count
Store spectrum( ) in output
file
End

FIG. 13

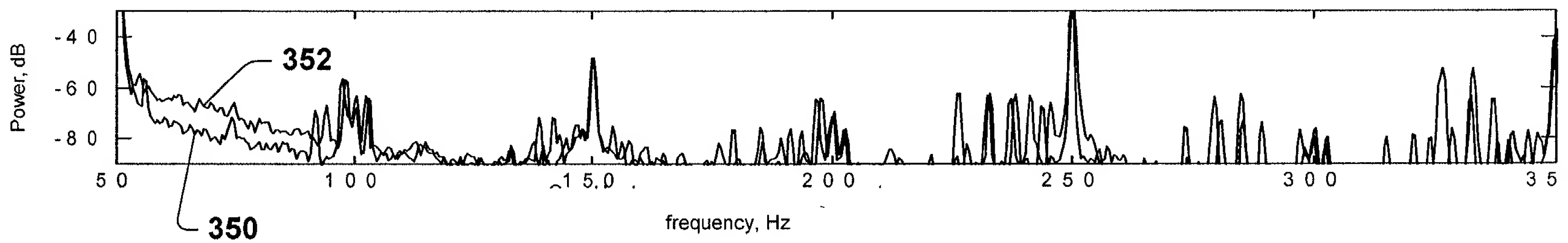


Fig. 14a

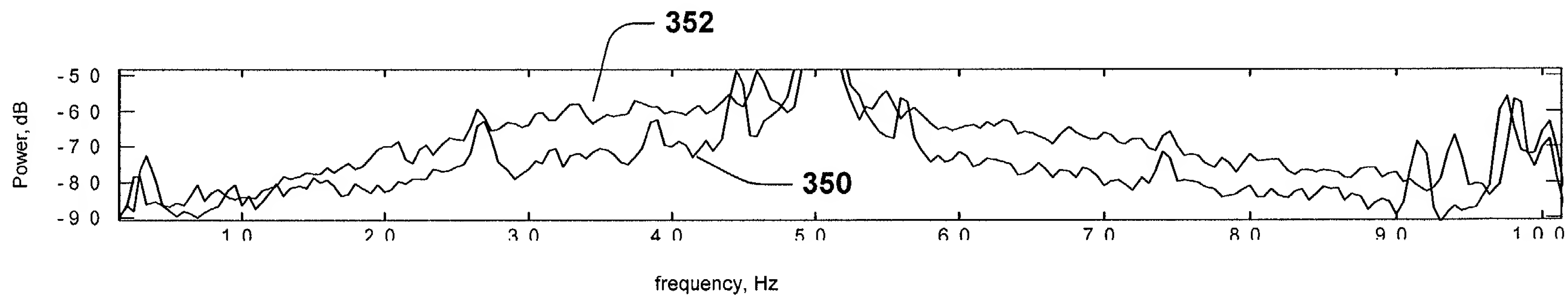


Fig. 14b

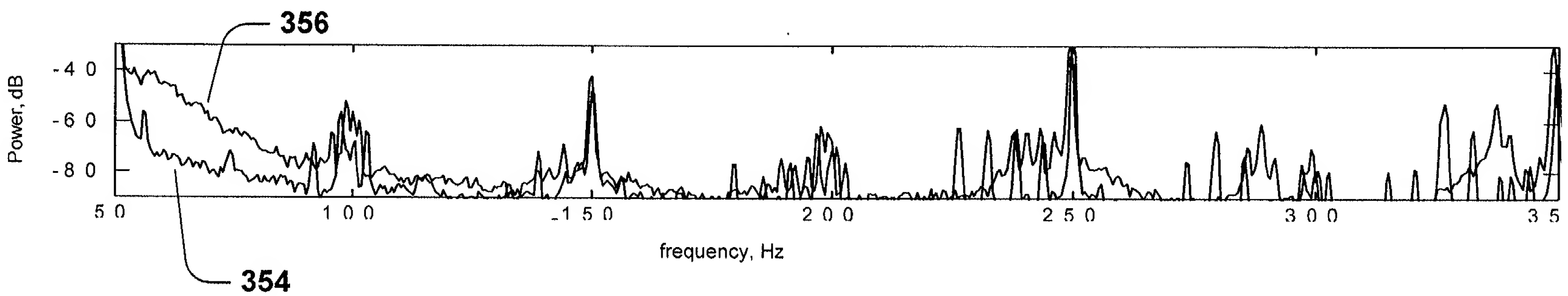


Fig. 14c

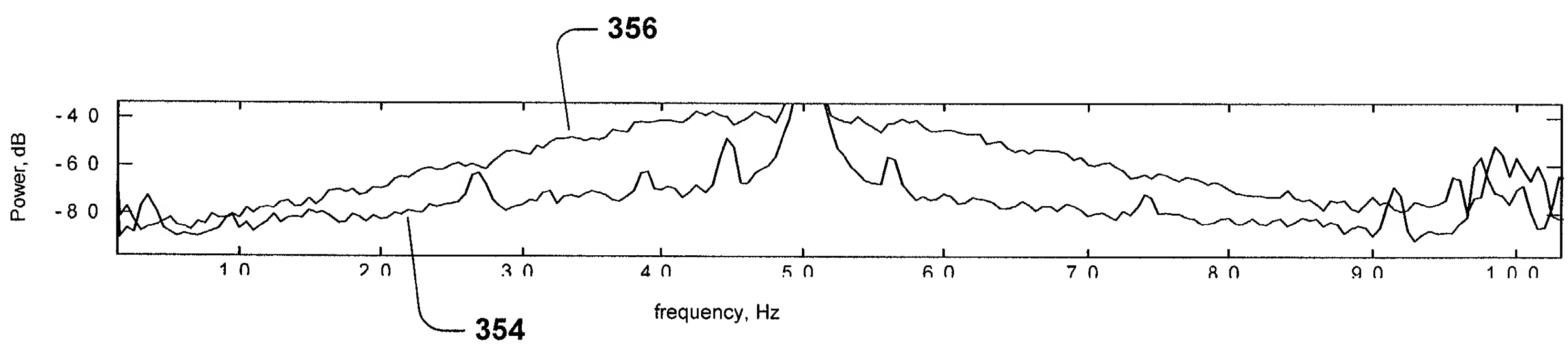


Fig. 14d

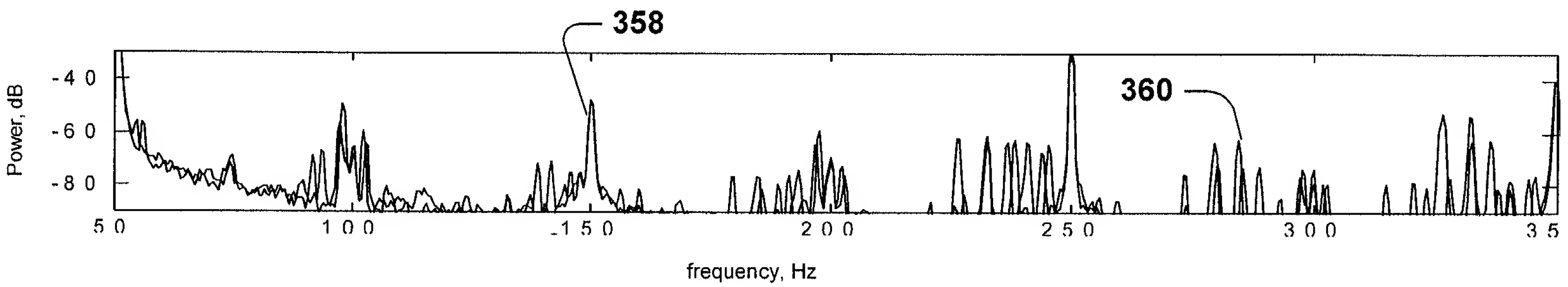


Fig. 14e

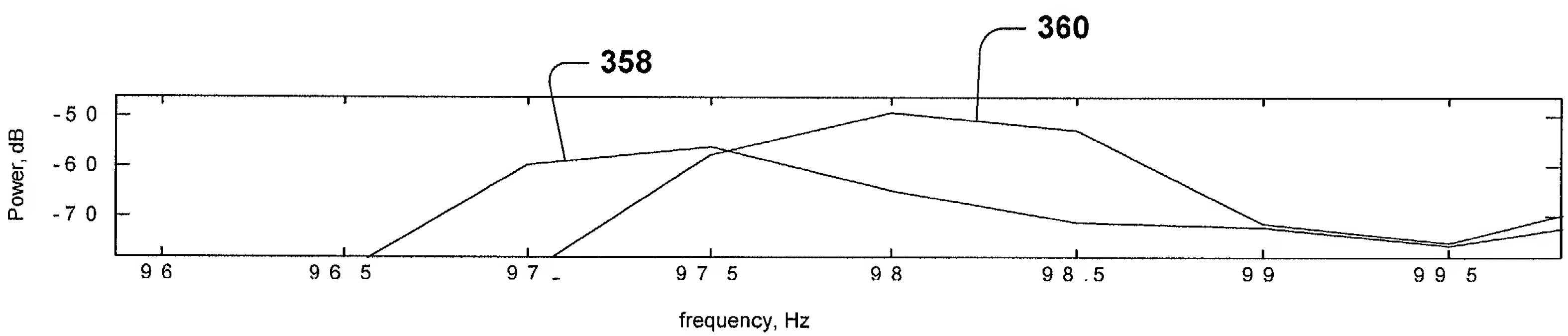


Fig. 14f

400

402

f_0	f_1	f_2	f_3	f_4	•	•	•	f_n	
A_3	A_{34}	A_{67}	A_{78}	A_{84}	•	•	•	A_K	HEALTHY PUMP
A_{34}	A_{-68}	A_{-90}	A_{-65}	A_{45}	•	•	•	A_H	PUMP FAULT 1
A_{56}	A_{45}	A_{45}	A_{56}	A_{78}	•	•	•	A_X	PUMP FAULT 2
A_{-23}	A_{45}	A_7	A_{90}	A_{12}	•	•	•	A_Z	PUMP FAULT 3
A_{67}	A_{36}	A_3	A_{45}	A_{47}	•	•	•	A_X	PUMP FAULT 4
A_{78}	A_{67}	A_{12}	A_{67}	A_{37}	•	•	•	A_C	PUMP FAULT 5
A_{234}	A_{27}	A_{478}	A_{24}	A_{127}	•	•	•	A_Q	PUMP FAULT 6
A_{-98}	A_{78}	A_{26}	A_{12}	A_{128}	•	•	•	A_B	PUMP FAULT 7
A_{26}	A_{96}	A_{83}	A_{56}	A_{234}	•	•	•	A_M	PUMP FAULT 8
A_4	A_{32}	A_{187}	A_{56}	A_{34}	•	•	•	A_I	PUMP FAULT 9
A_0	A_{16}	A_{73}	A_{76}	A_{33}	•	•	•	A_E	PUMP FAULT N-1
A_{75}	A_{17}	A_{45}	A_{69}	A_{44}	•	•	•	A_Q	PUMP FAULT N

404

FIG. 14g

Divide the collected data into equal sets. Perform Hanning Windowing , FFT on each set to obtain 'Smoothed Periodogram' by averaging all the sets.

↓

Identify the fundamental supply component by locating the component having maximum amplitude in the stator current spectrum. Record its frequency (F_s) and amplitude (*FsAmp*). Locate multiples of F_s (supply related components)

↓

Calculate synchronous speed of the motor, $F_{sync} = F_s$ /polepairs. Locate the *slip frequency related* components by searching between ($mF_s - 2F_{slmin}$) and ($mF_s - 10F_{slmax}$) for m = 3,5 and 7.

$F_{slmax} = F_{sync}$ * maximum slip

$F_{slmin} = F_{sync}$ * minimum slip

↓

Calculate the *slip* from the above components. Locate $F_s + F_r$ and record its amplitude *FrAmp* where $F_r = F_{sync} * (1 - slip)$

↓

Search and locate the remaining 'slip frequency related' harmonics adjacent to other supply related components.

↓

Eliminate all the 'slip frequency related' harmonics between $F_s/2$ and $3F_s/2$ and measure the noise in the region.

noise_1 = [*sum of noise between* {(F_s - L -J) and (F_s - L)}+ {(F_s + L) and (F_s + L+J)}]

noise_i = [*sum of noise between* {(F_s - L -J(i+1)) and (F_s - L-Ji)}+ {(F_s + L+Ji) and (F_s + L+J(i+1))}]

for i = 2 to 5, L=6*resolution, and J= F_s /10

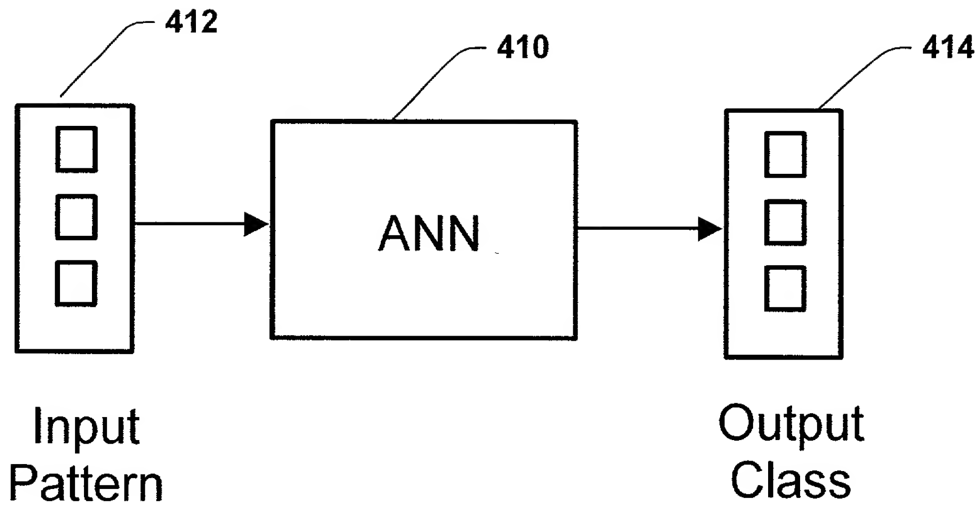
328

↓

Preprocess the attributes ***slip*** **,*FsAmp*, *SigAmp*, *Noise_1*, *Noise_2*, *Noise_3*, *Noise_4*** and ***Noise_5*** to make them acceptable by the Neural Network algorithms.

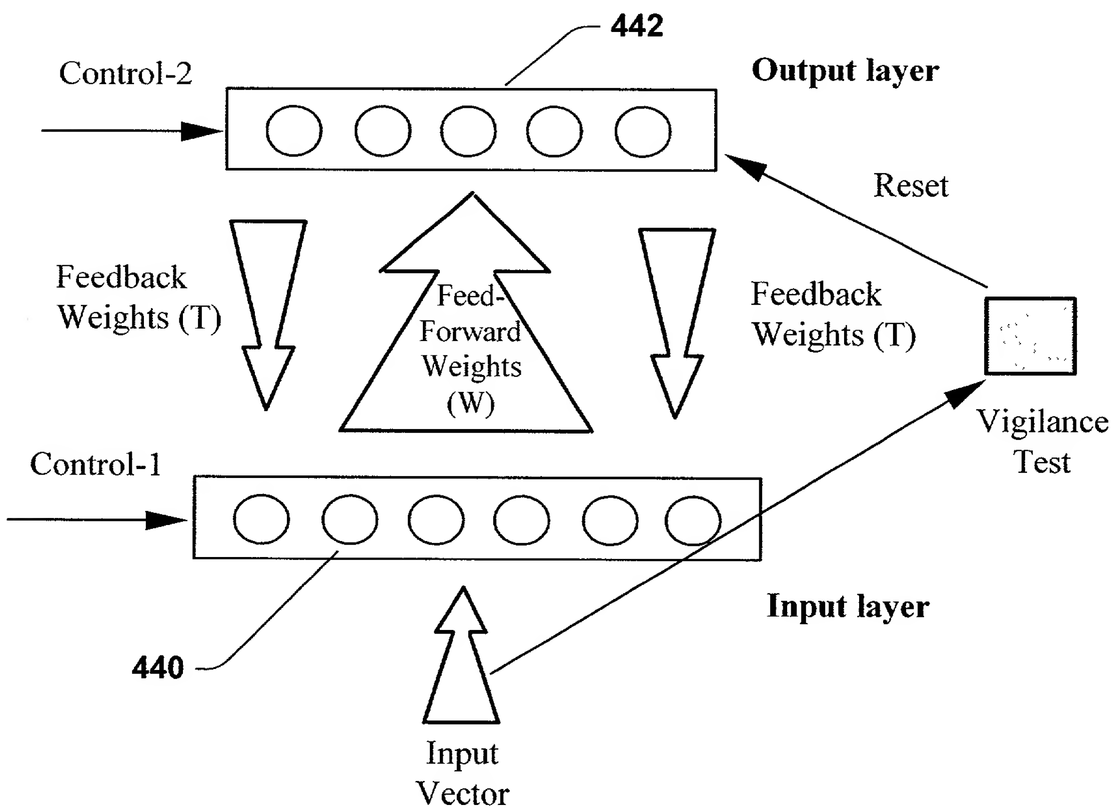
330

FIG. 15



412
410
414
ANN
Input Pattern
Output Class

Fig. 16



442
Control-2
Output layer
Reset
Feedback Weights (T)
Feed-Forward Weights (W)
Feedback Weights (T)
Vigilance Test
Control-1
Input layer
440
Input Vector

Fig. 17

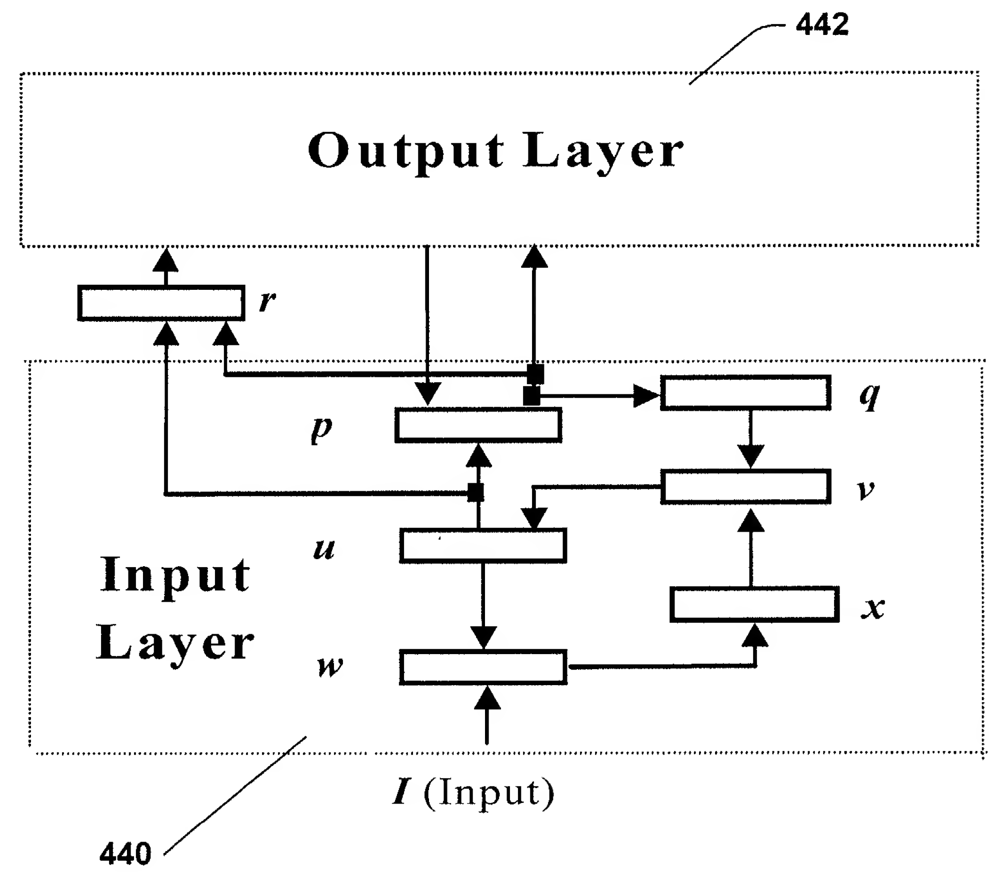


Fig. 18

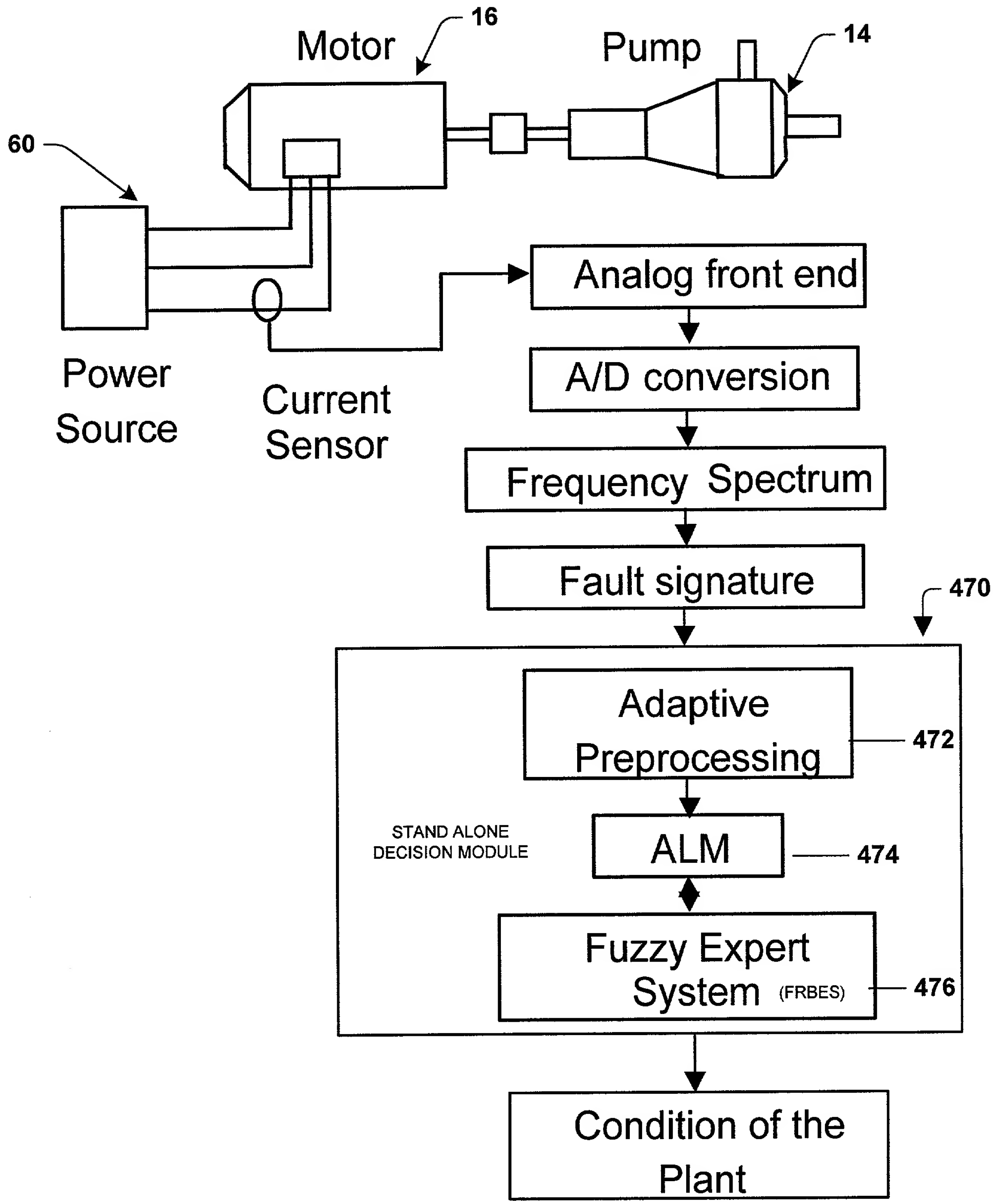

Motor
16
Pump
14
60
Analog front end
A/D conversion
Frequency Spectrum
Fault signature
Power Source
Current Sensor
470
Adaptive Preprocessing
472
STAND ALONE DECISION MODULE
ALM
474
Fuzzy Expert System (FRBES)
476
Condition of the Plant

Fig. 19

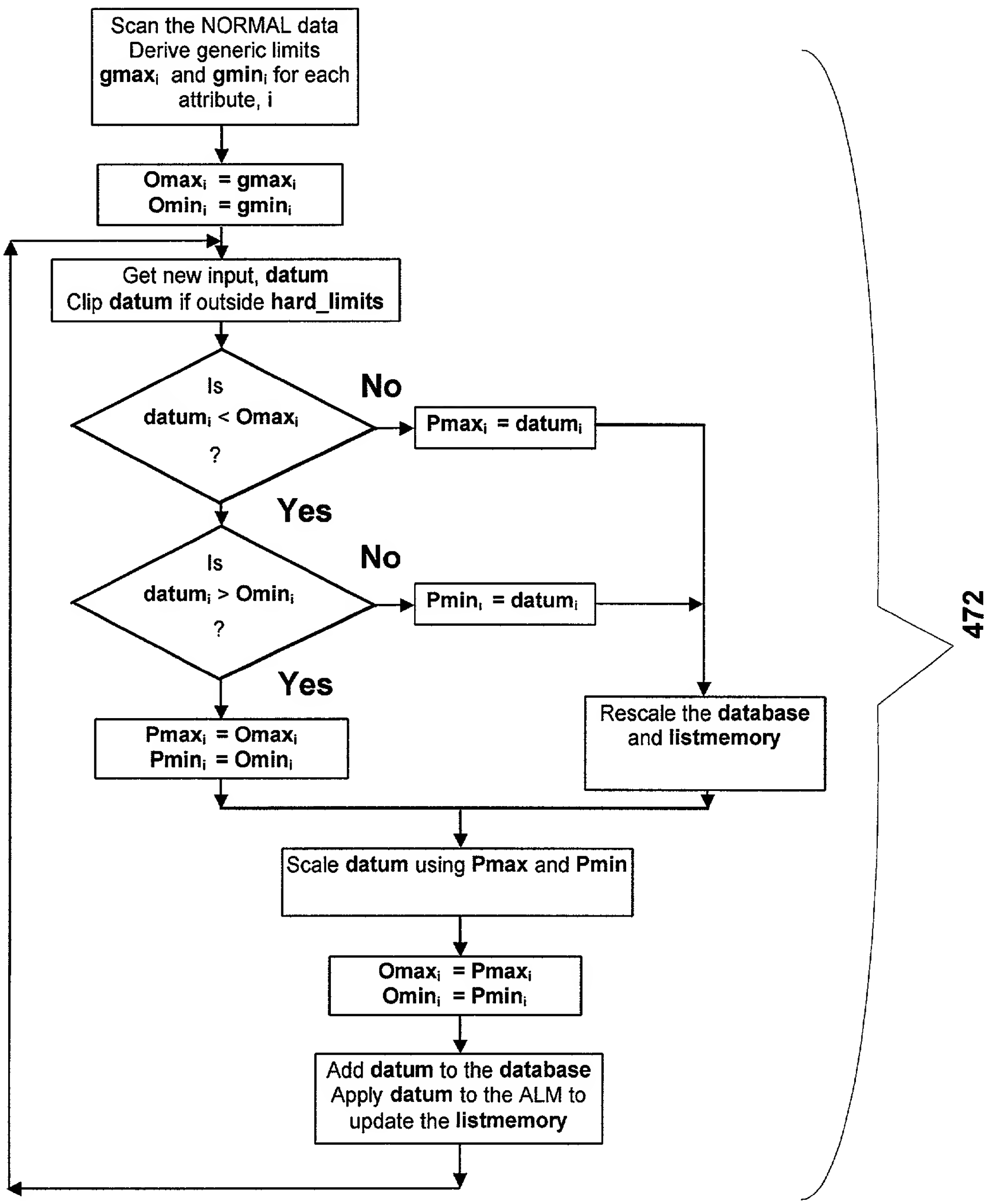

Scan the NORMAL data
Derive generic limits
gmaxi and gmini for each attribute, i
Omaxi = gmaxi
Omini = gmini
Get new input, datum
Clip datum if outside hard_limits
Is datumi < Omaxi ?
No
Pmaxi = datumi
Yes
Is datumi > Omini ?
No
Pmini = datumi
Yes
Pmaxi = Omaxi
Pmini = Omini
Rescale the database and listmemory
Scale datum using Pmax and Pmin
Omaxi = Pmaxi
Omini = Pmini
Add datum to the database
Apply datum to the ALM to update the listmemory
472

Fig. 20

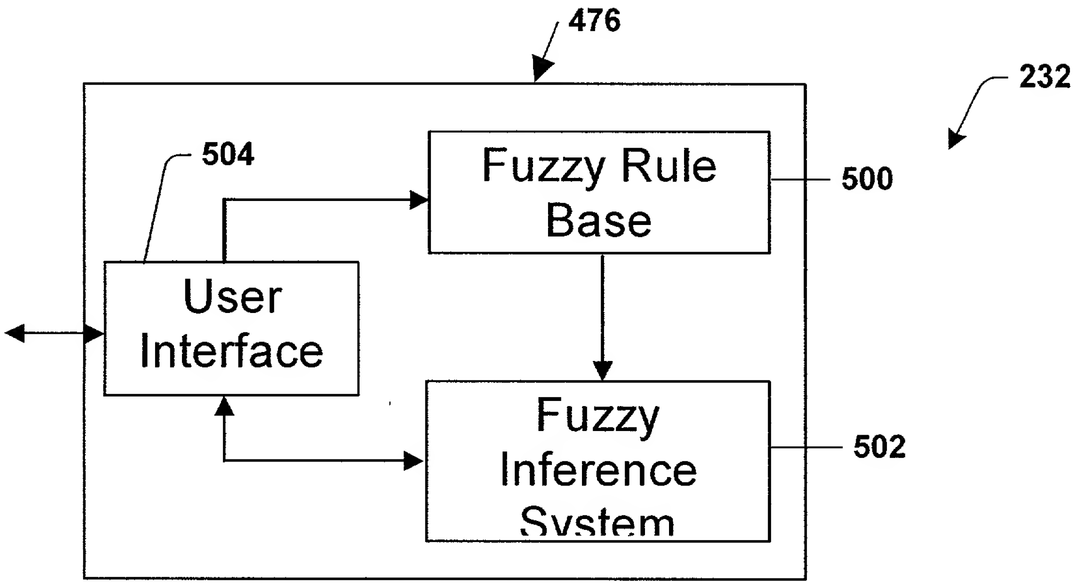

476
232
504
Fuzzy Rule Base
500
User Interface
Fuzzy Inference System
502

Fig. 21

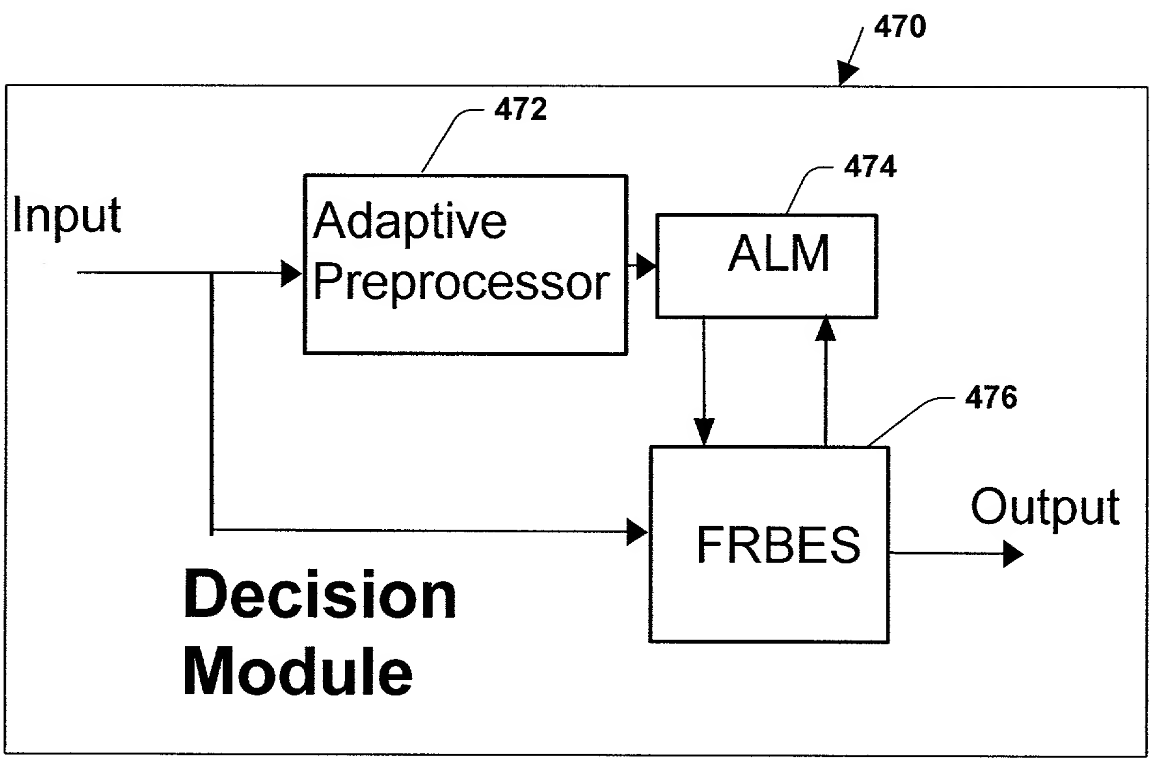

470
472
474
Input
Adaptive Preprocessor
ALM
476
FRBES
Output
Decision Module

Fig. 22

IF all the attributes are *NORMAL* **THEN** condition is normal
IF slip is *SLLO* and noise_2 is *HI* **THEN** condition is low-cav
IF noise_4 and noise_5 are *VERHI* **THEN** condition is sev-cav
IF noise_4 and noise_5 are *HI* **THEN** condition is sev-cav
IF FsAmp is *SLLO* and noise_5 are *SLHI* **THEN** condition is sev-cav
IF FsAmp is *LO* and noise_5 is *SLHI* **THEN** condition is sev-cav
IF FsAmp is *VERLO* and noise_5 is *SLHI* **THEN** condition is sev-cav
IF FsAmp is *SLLO* and noise_4 are *HI* **THEN** condition is sev-cav
IF FsAmp is *LO* and noise_4 is *HI* **THEN** condition is sev-cav
IF FsAmp is *LO* and noise_4 is *VERHI* **THEN** condition is sev-cav
IF FsAmp is *SLLO* and slip is *SLLO* and noise_4 is *NORMAL* and noise_5 is *NORMAL* **THEN** condition is low-block
IF FsAmp is *LO* and noise_4 is *NORMAL* and noise_5 is *NORMAL* **THEN** condition is sev-block
IF slip and FsAmp are *VERLO* **THEN** condition is sev-block
IF FrAmp is *HI* **THEN** condition is impel-fault
IF framp is *VERHI* **THEN** condition is impel-fault

Fig. 23

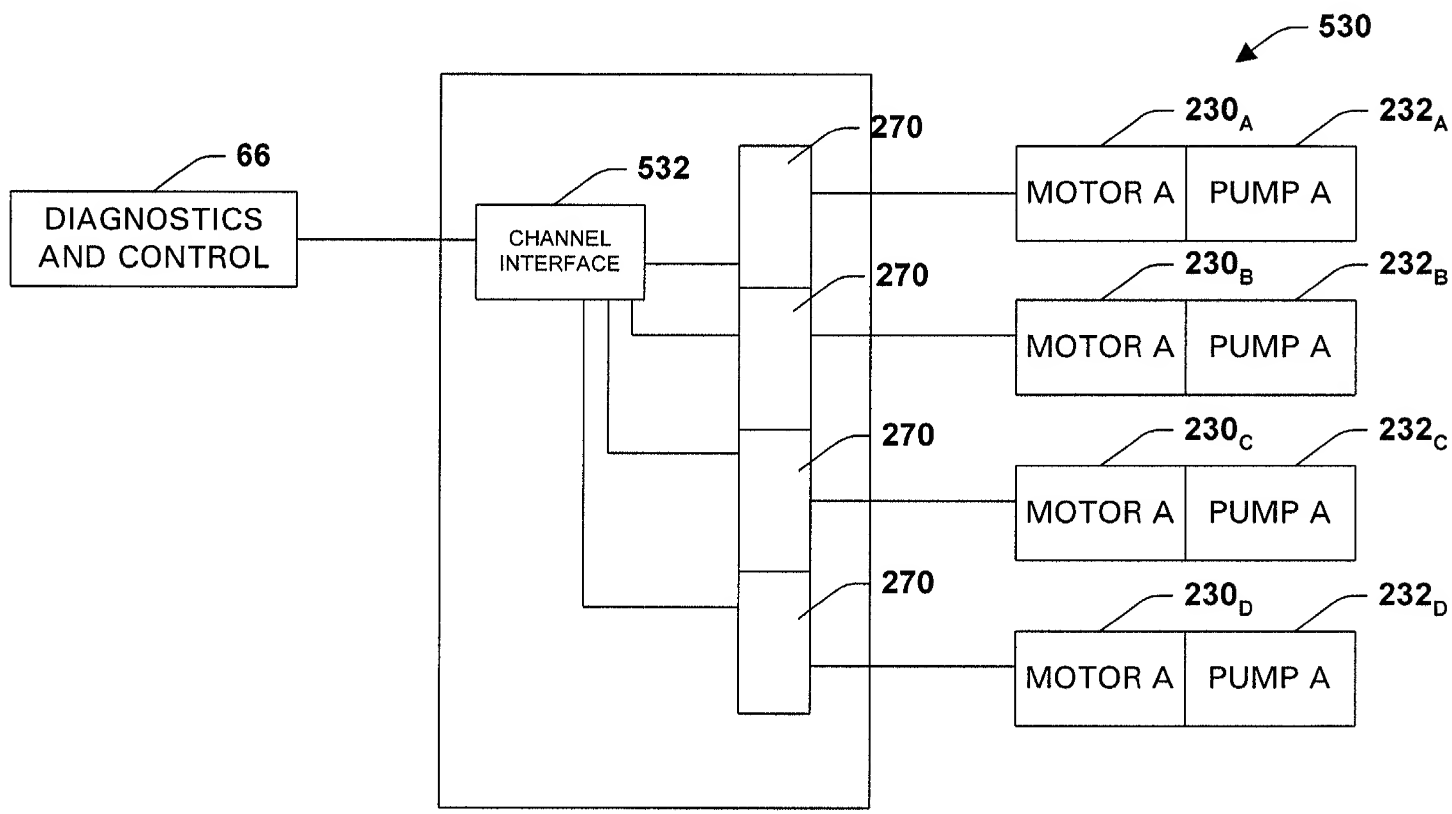

530
DIAGNOSTICS AND CONTROL
66
CHANNEL INTERFACE
532
270
270
270
270
MOTOR A
PUMP A
230A
232A
MOTOR A
PUMP A
230B
232B
MOTOR A
PUMP A
230C
232C
MOTOR A
PUMP A
230D
232D

Fig. 24

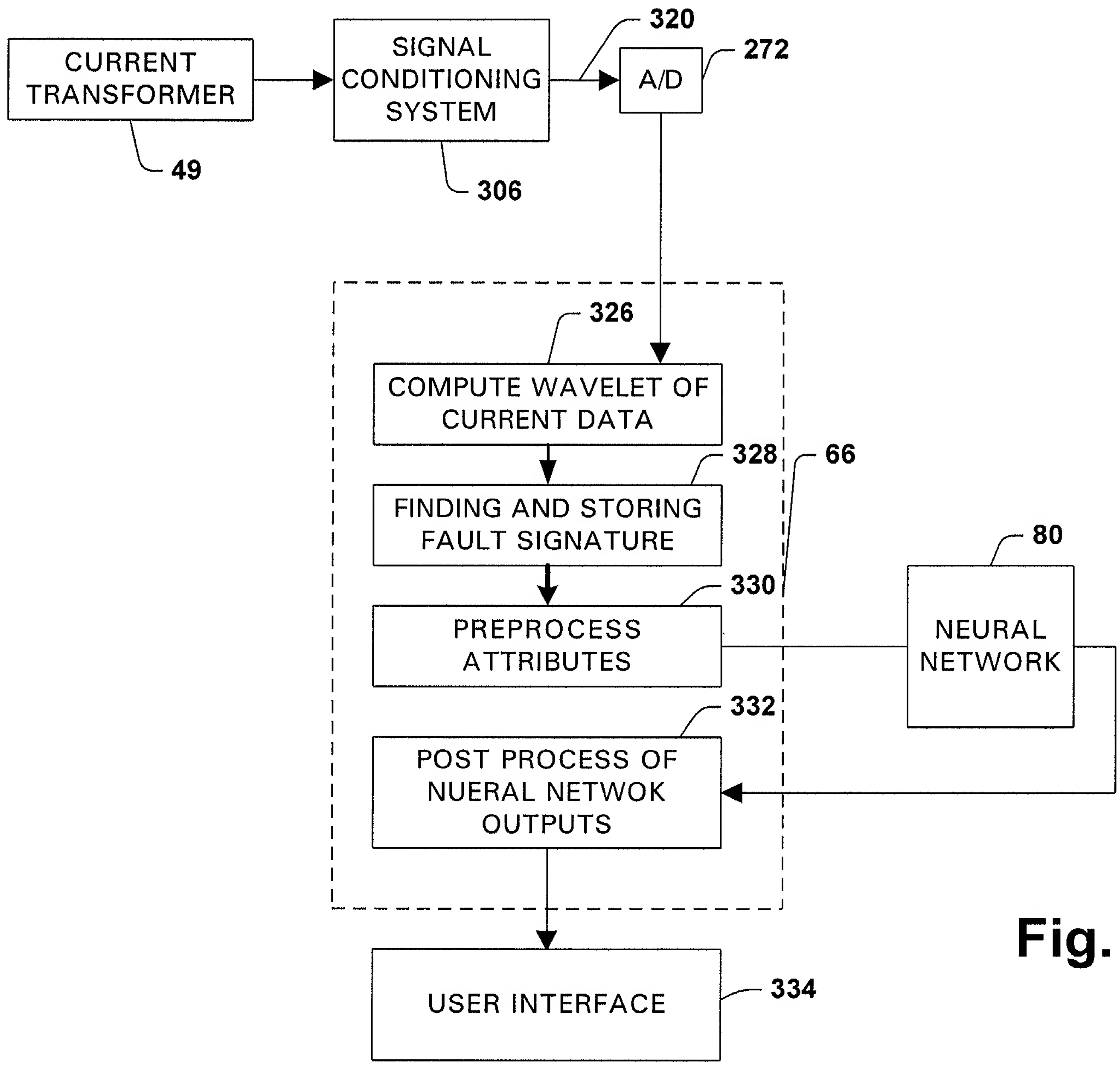

CURRENT TRANSFORMER
49
SIGNAL CONDITIONING SYSTEM
306
320
A/D
272
326
COMPUTE WAVELET OF CURRENT DATA
328
66
FINDING AND STORING FAULT SIGNATURE
80
330
PREPROCESS ATTRIBUTES
NEURAL NETWORK
332
POST PROCESS OF NUERAL NETWOK OUTPUTS
USER INTERFACE
334

Fig. 25

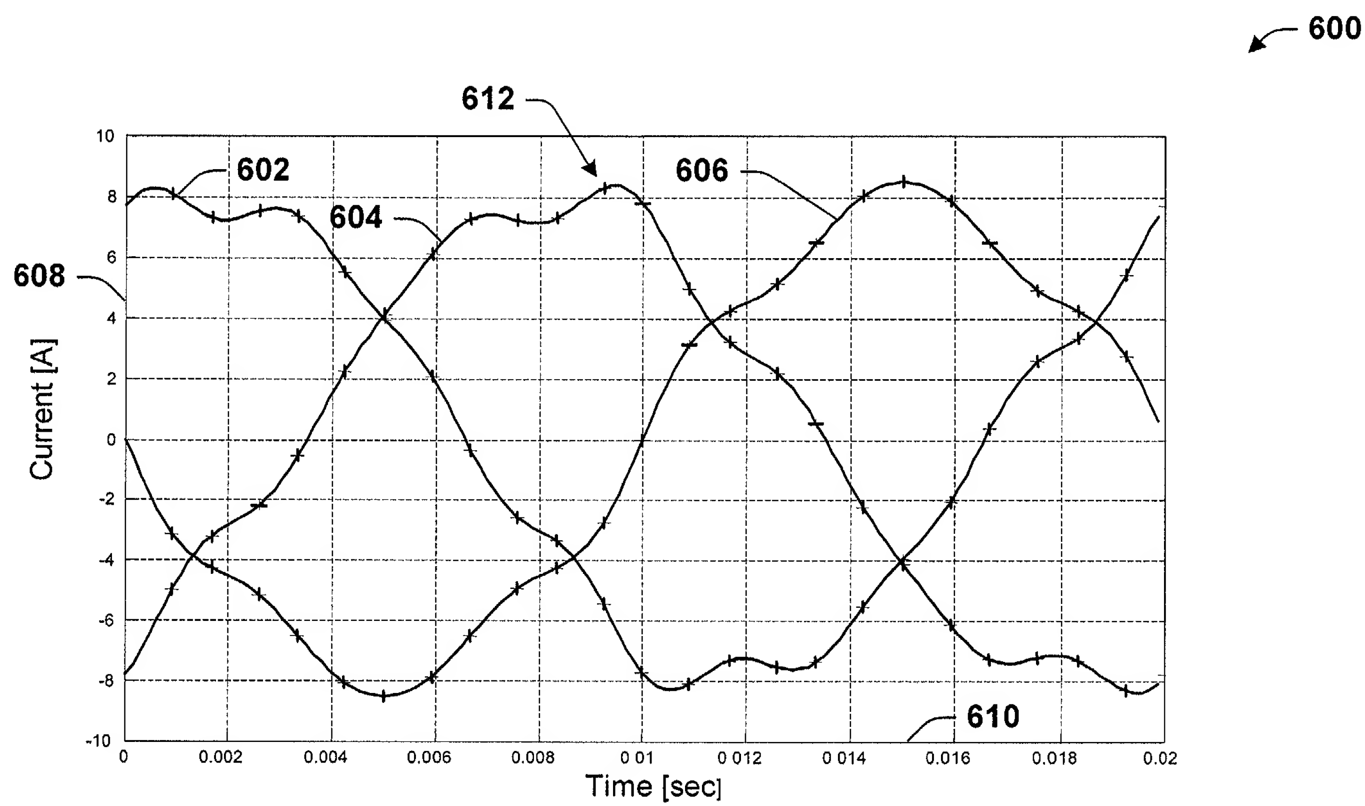
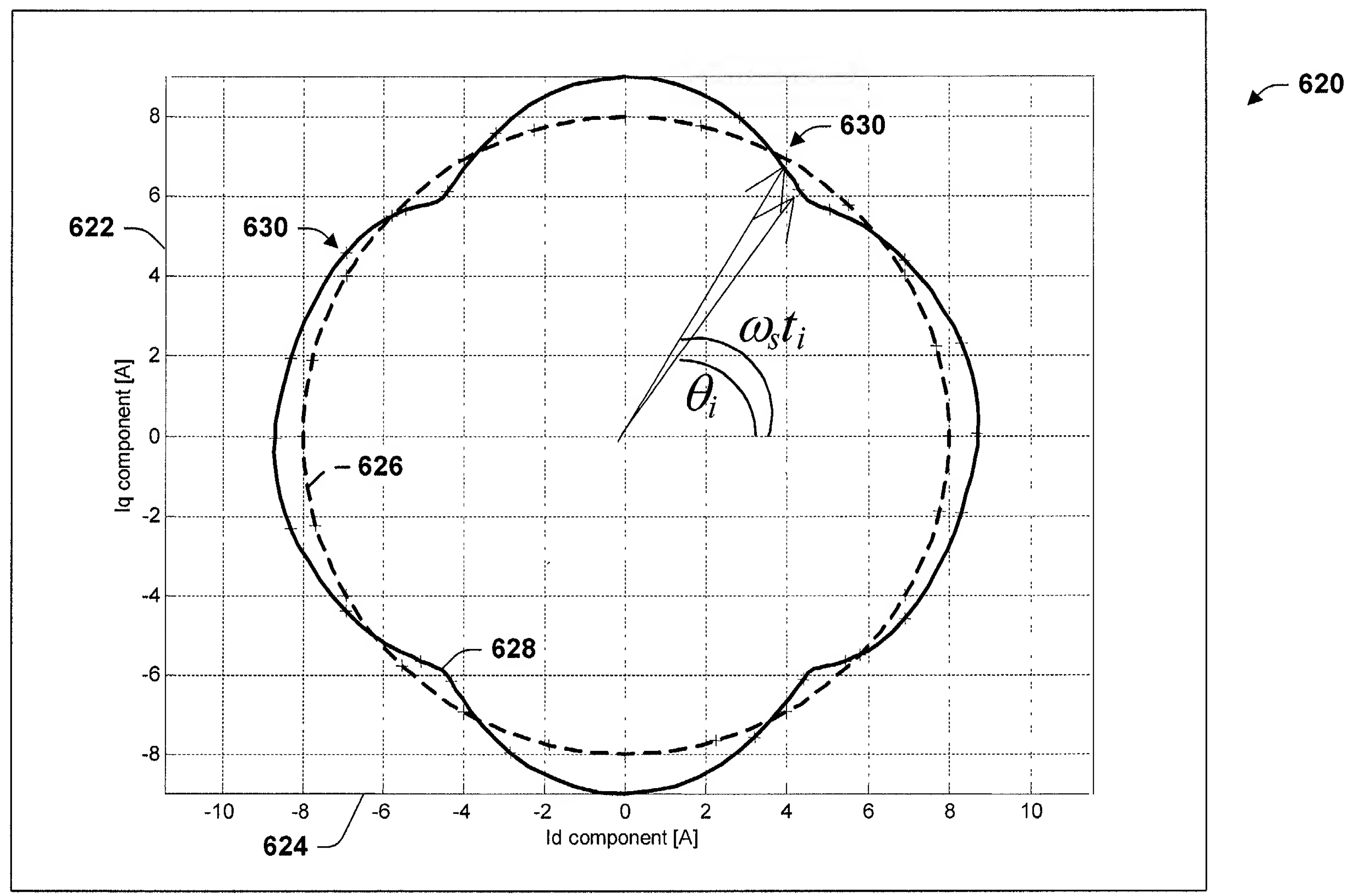

600
612
602
604
606
608
610
Current [A]
Time [sec]
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
0.018
0.02

FIG. 26



620
630
630
622
626
628
624
$\omega_s t_i$
θ_i
Iq component [A]
Id component [A]
8
6
4
2
0
-2
-4
-6
-8
-10
10

FIG. 27

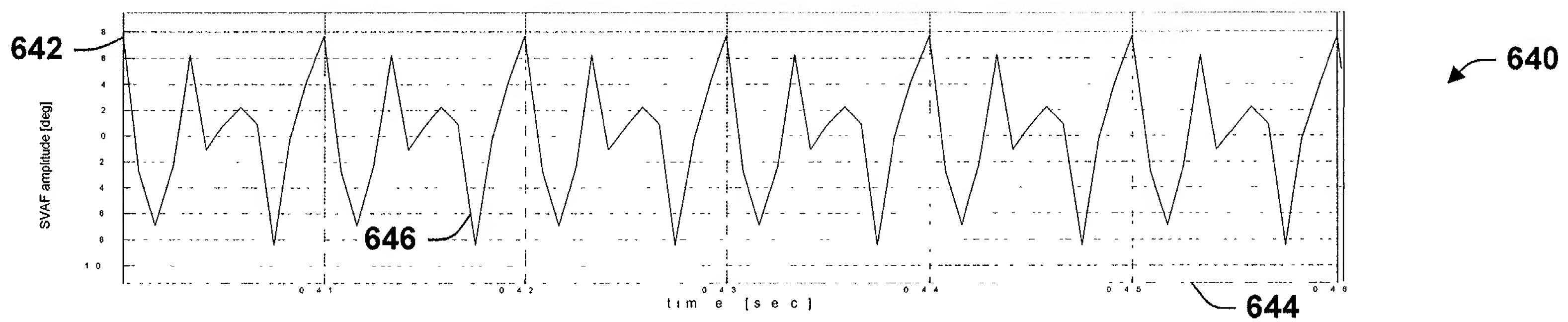

640
642
646
644
SVAF amplitude [deg]
time [sec]

FIG. 28

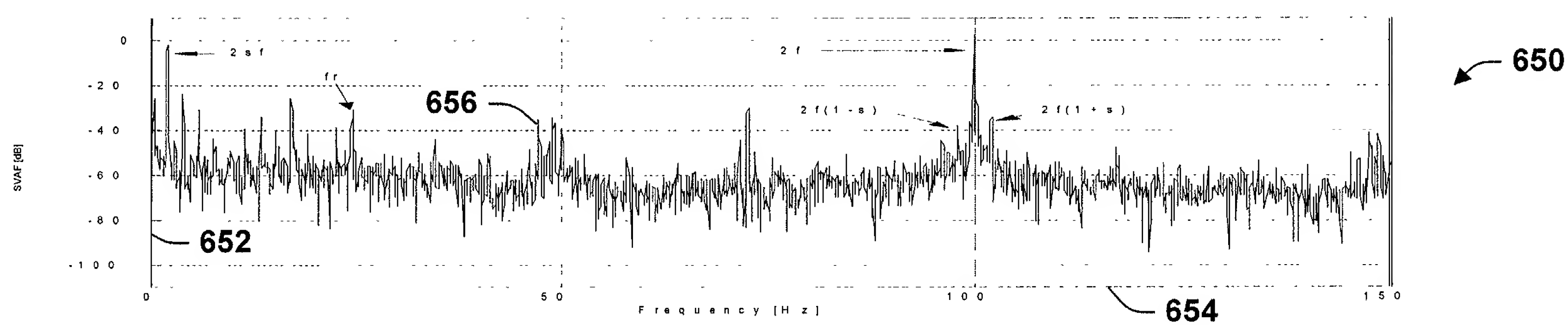
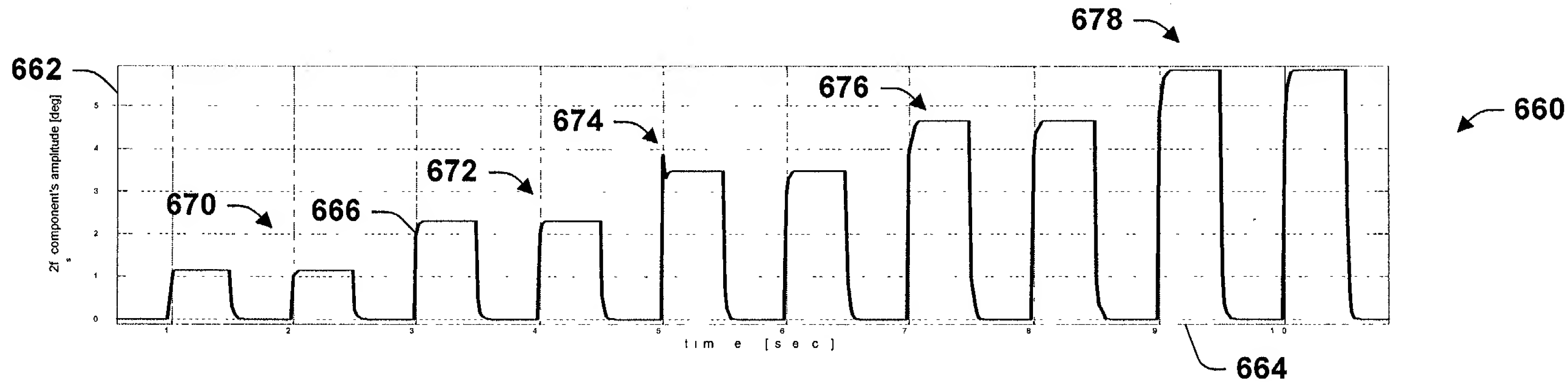
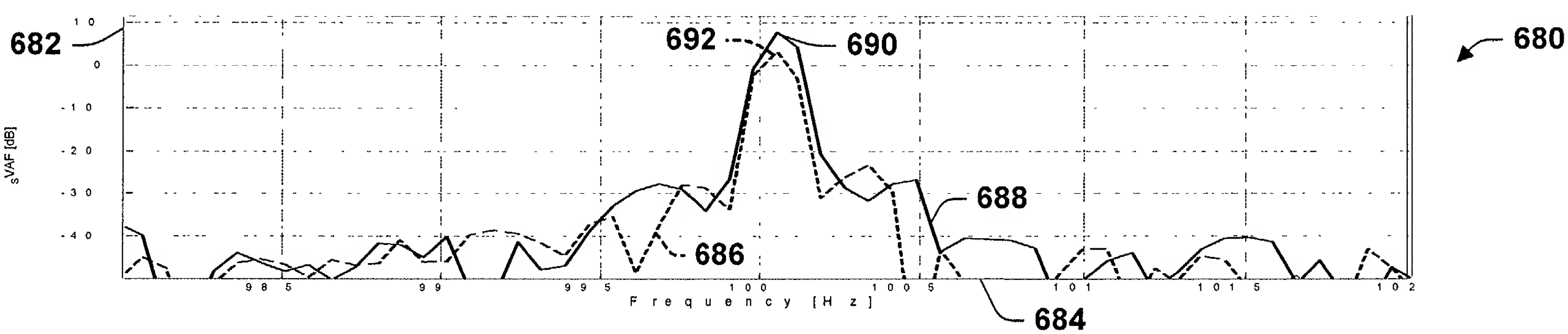

650
2sf
fr
656
2f
2f(1-s)
2f(1+s)
652
654
SVAF [dB]
Frequency [Hz]

FIG. 29



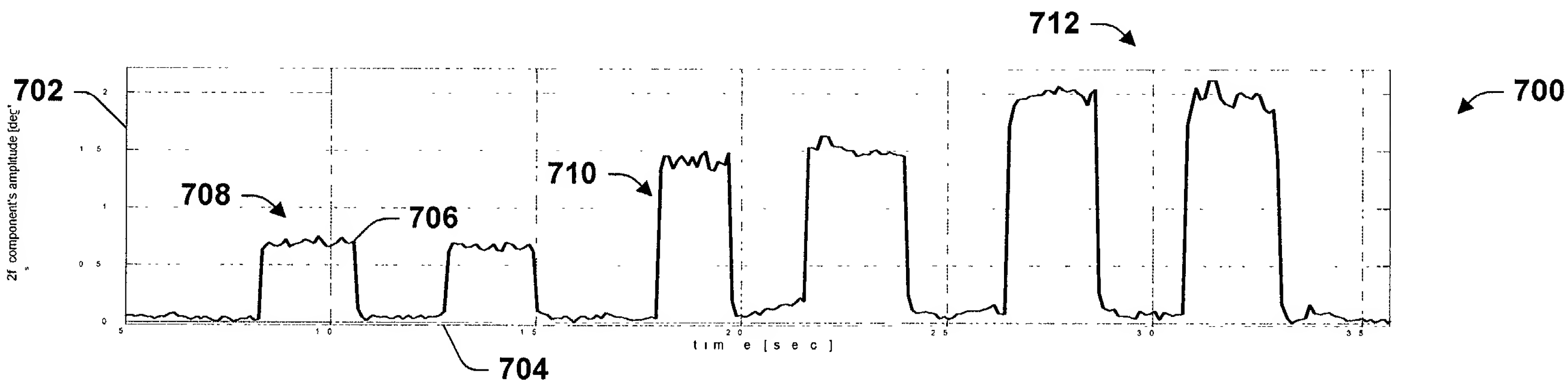
662
660
678
676
674
672
670
666
664
2f component's amplitude [deg]
time [sec]

FIG. 30



682
680
692
690
688
686
684
VAF [dB]
Frequency [Hz]

FIG. 31



700
702
704
706
708
710
712
2f component's amplitude [deg]
time [sec]

FIG. 32

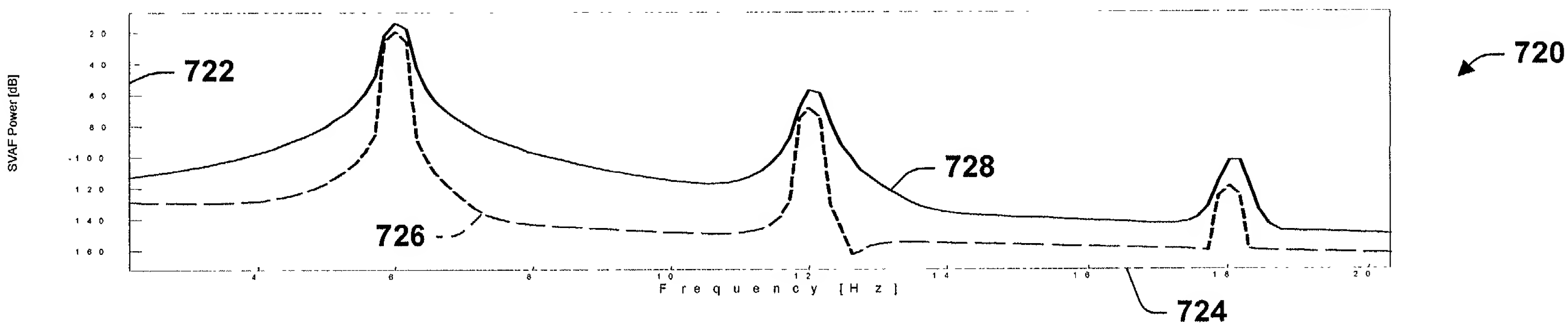

720
722
726
728
724
SVAF Power [dB]
Frequency [Hz]

FIG. 33

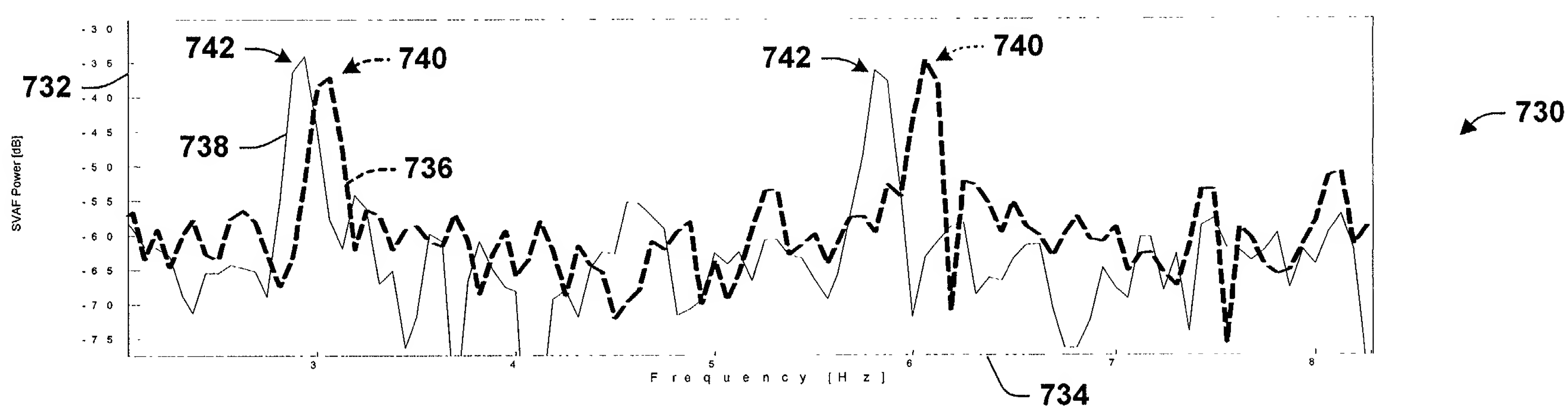

730
732
742
740
738
736
734
SVAF Power [dB]
Frequency [Hz]

FIG. 34

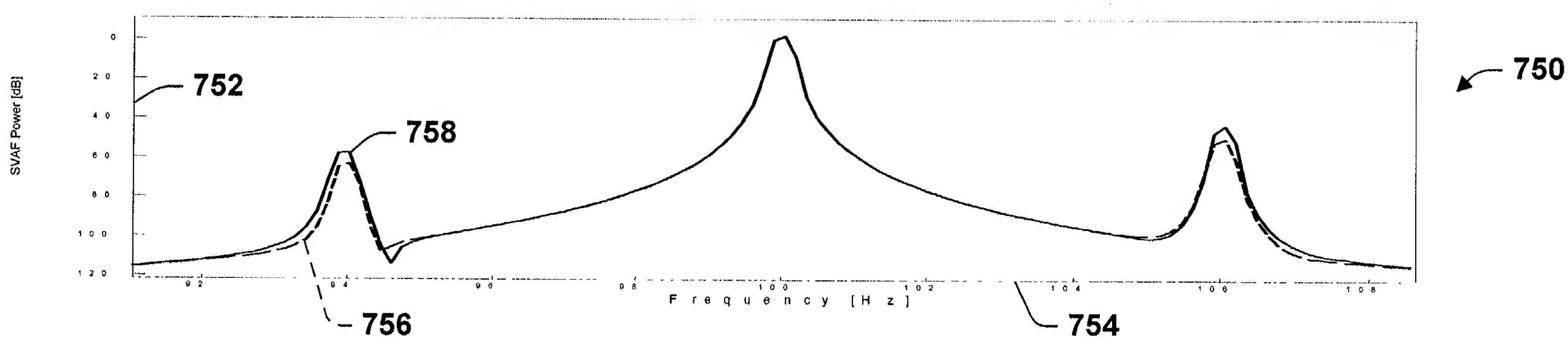

750
752
758
756
754
SVAF Power [dB]
Frequency [Hz]

FIG. 35

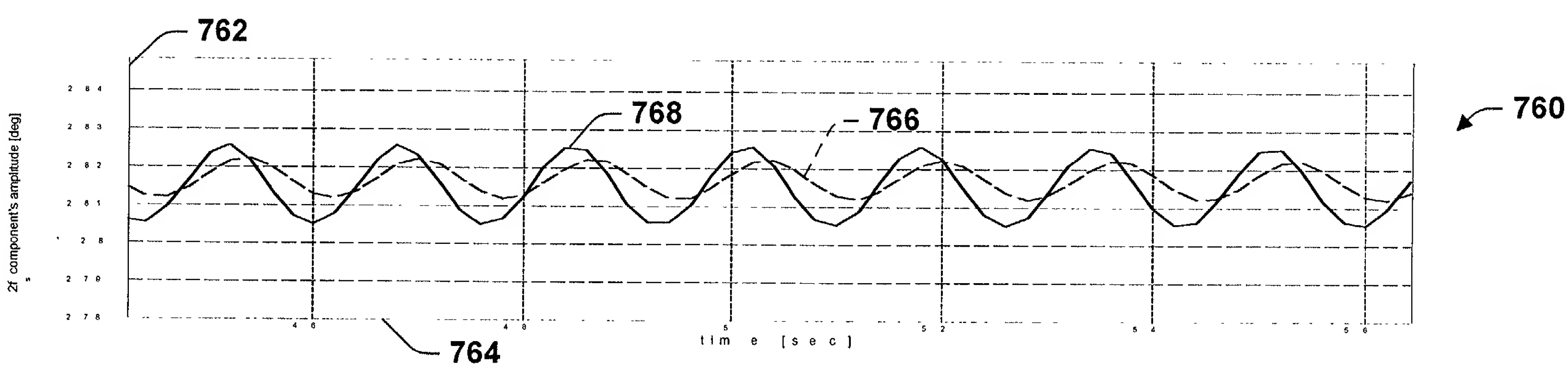

760
762
768
766
764
2f component's amplitude [deg]
time [sec]

FIG. 36

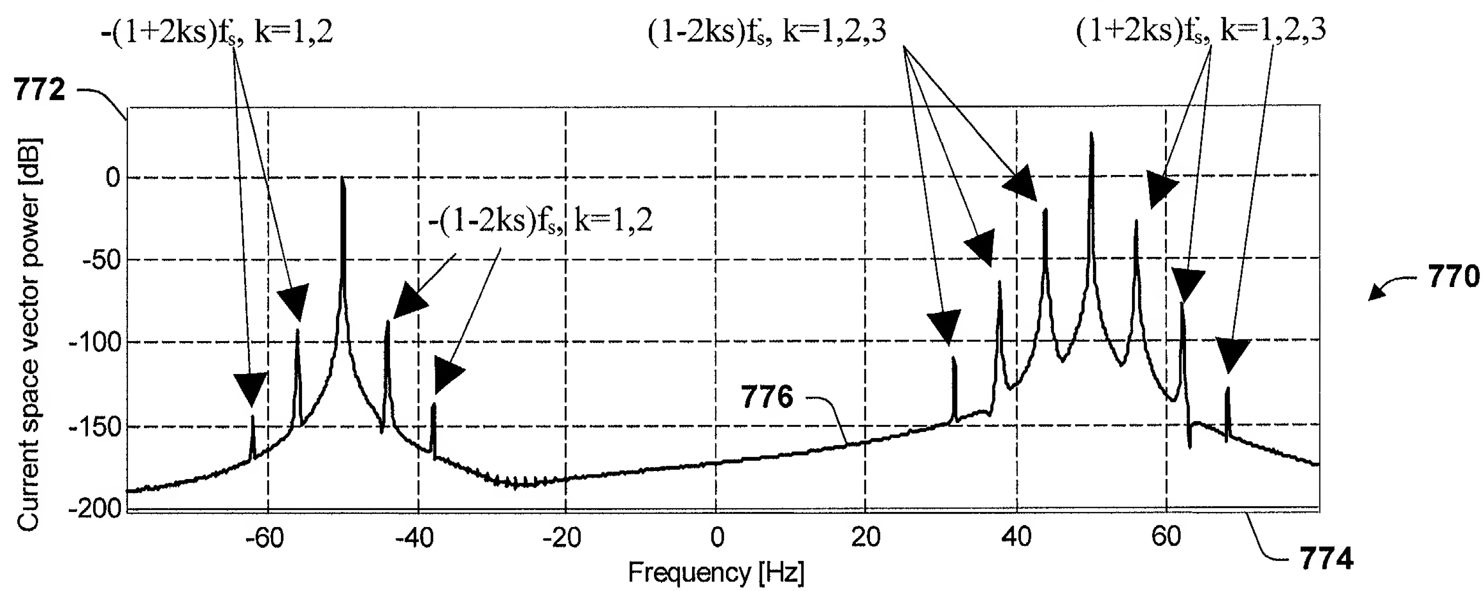

-(1+2ks)f_s, k=1,2
(1-2ks)f_s, k=1,2,3
(1+2ks)f_s, k=1,2,3
772
-(1-2ks)f_s, k=1,2
770
776
774
Current space vector power [dB]
0
-50
-100
-150
-200
-60
-40
-20
0
20
40
60
Frequency [Hz]

FIG. 37

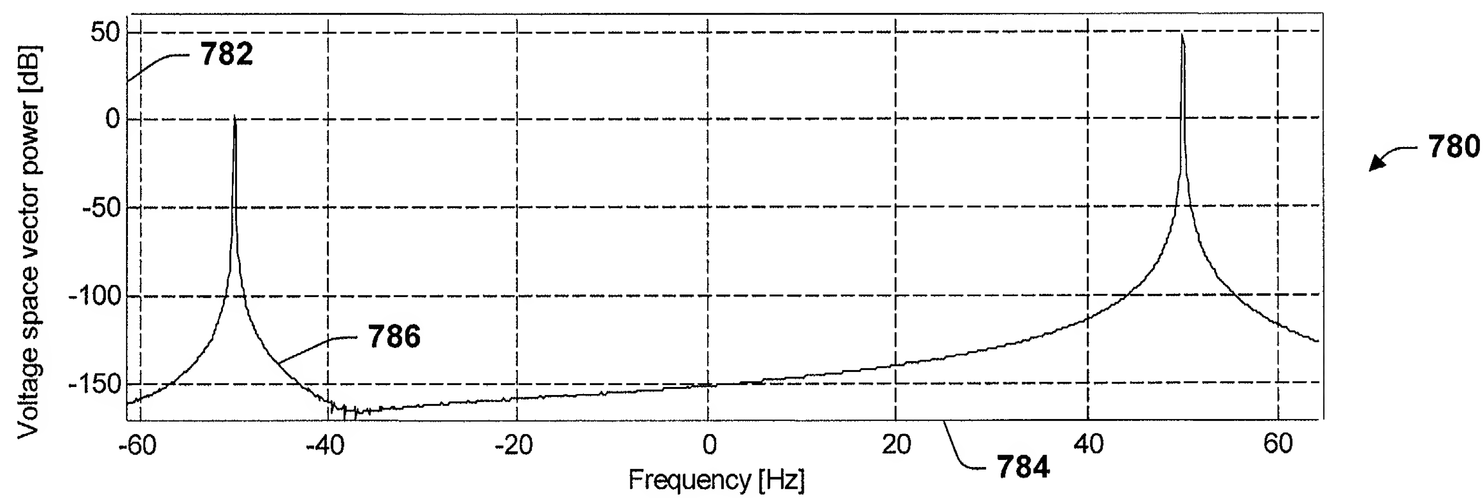

782
780
786
784
Voltage space vector power [dB]
50
0
-50
-100
-150
-60
-40
-20
0
20
40
60
Frequency [Hz]

FIG. 38

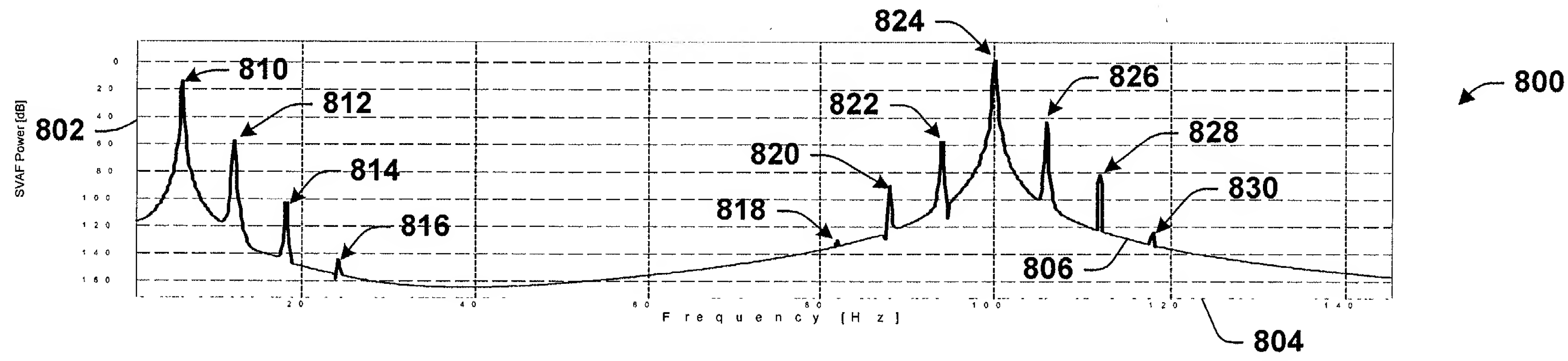

800
802
804
806
810
812
814
816
818
820
822
824
826
828
830
SVAF Power [dB]
0
20
40
60
80
100
120
140
160
20
40
60
80
100
120
140
Frequency [Hz]

FIG. 39

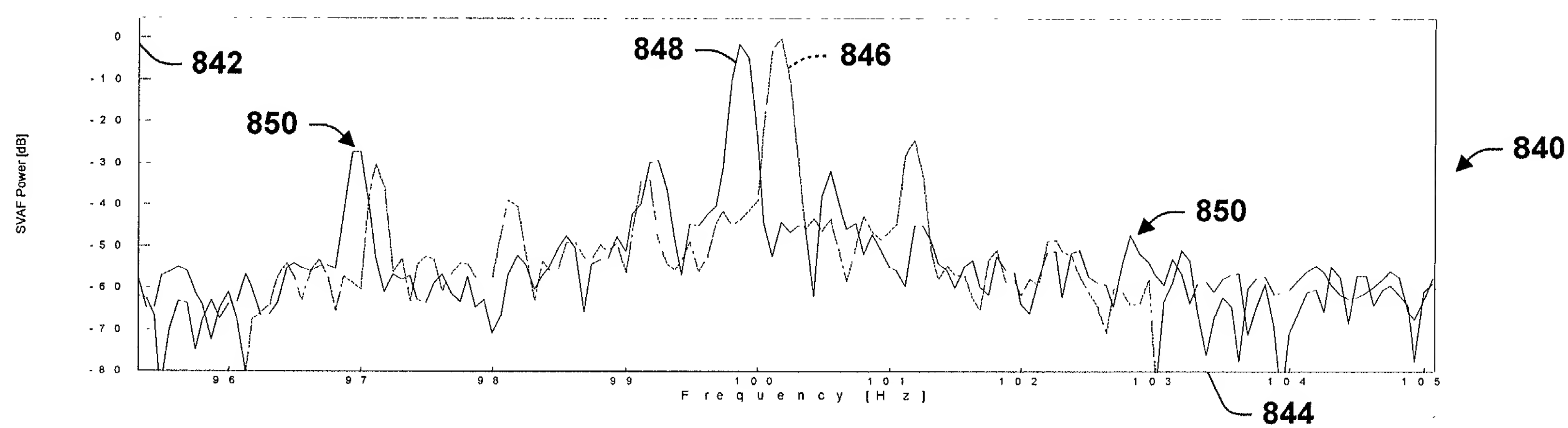
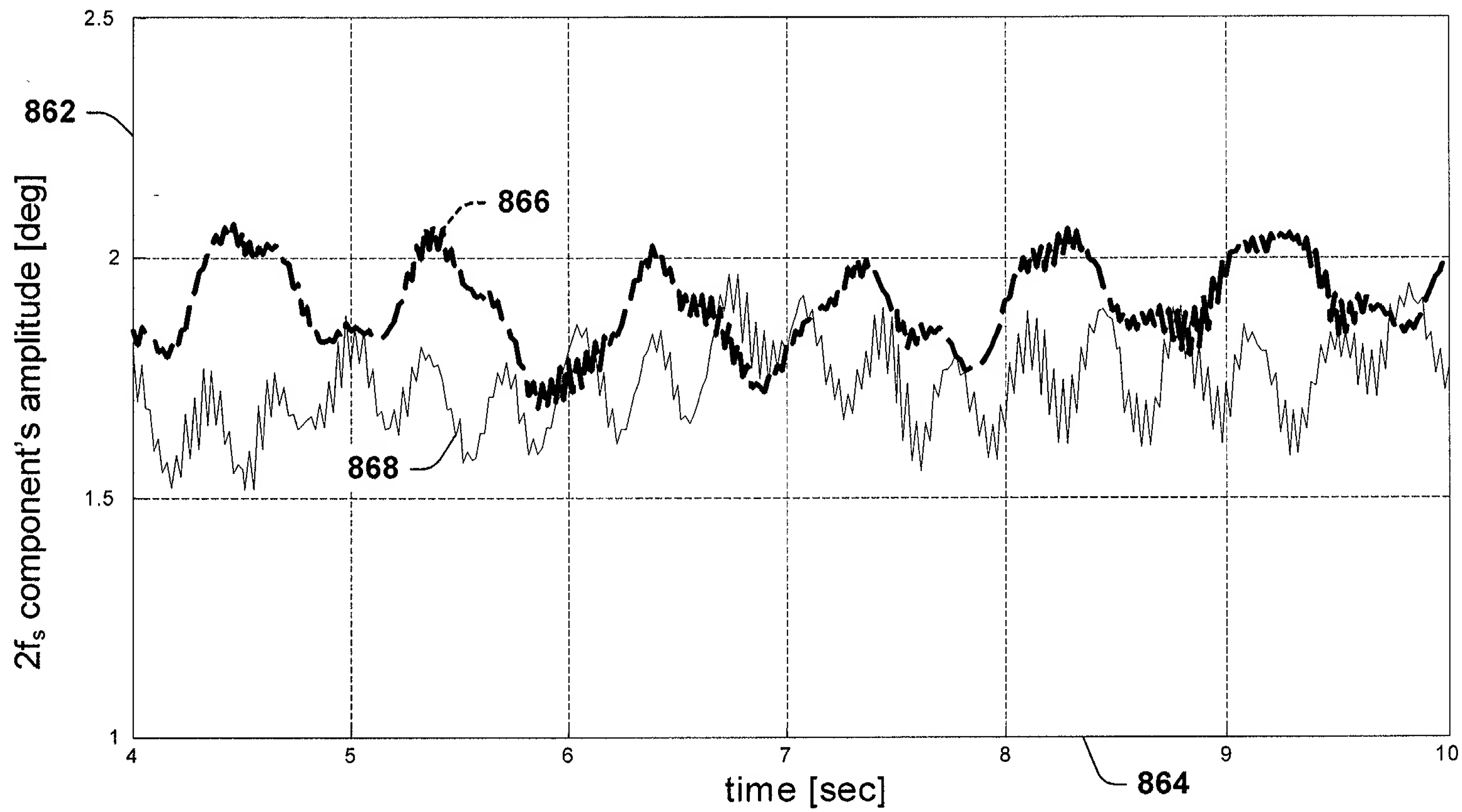

840
842
844
846
848
850
850
SVAF Power [dB]
0
-10
-20
-30
-40
-50
-60
-70
-80
96
97
98
99
100
101
102
103
104
105
Frequency [Hz]

FIG. 40



860
862
866
868
864
2.5
2
1.5
1
4
5
6
7
8
9
10
2fs component's amplitude [deg]
time [sec]

FIG. 41

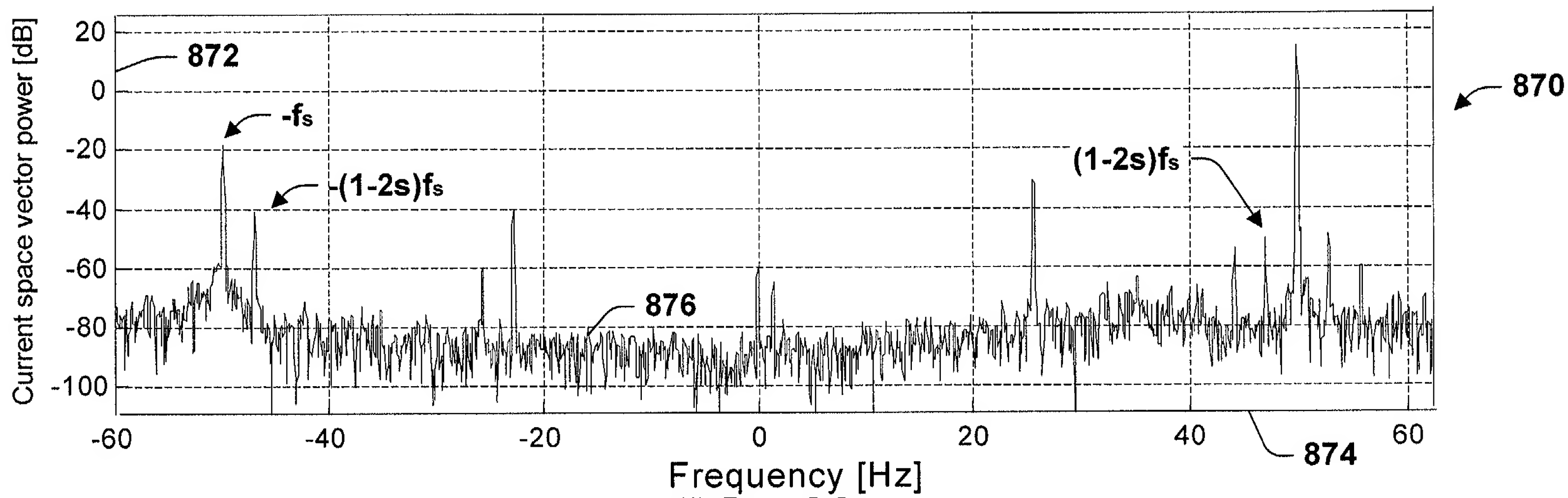

870
872
-fs
-(1-2s)fs
(1-2s)fs
876
874
Current space vector power [dB]
20
0
-20
-40
-60
-80
-100
-60
-40
-20
0
20
40
60
Frequency [Hz]

FIG. 42

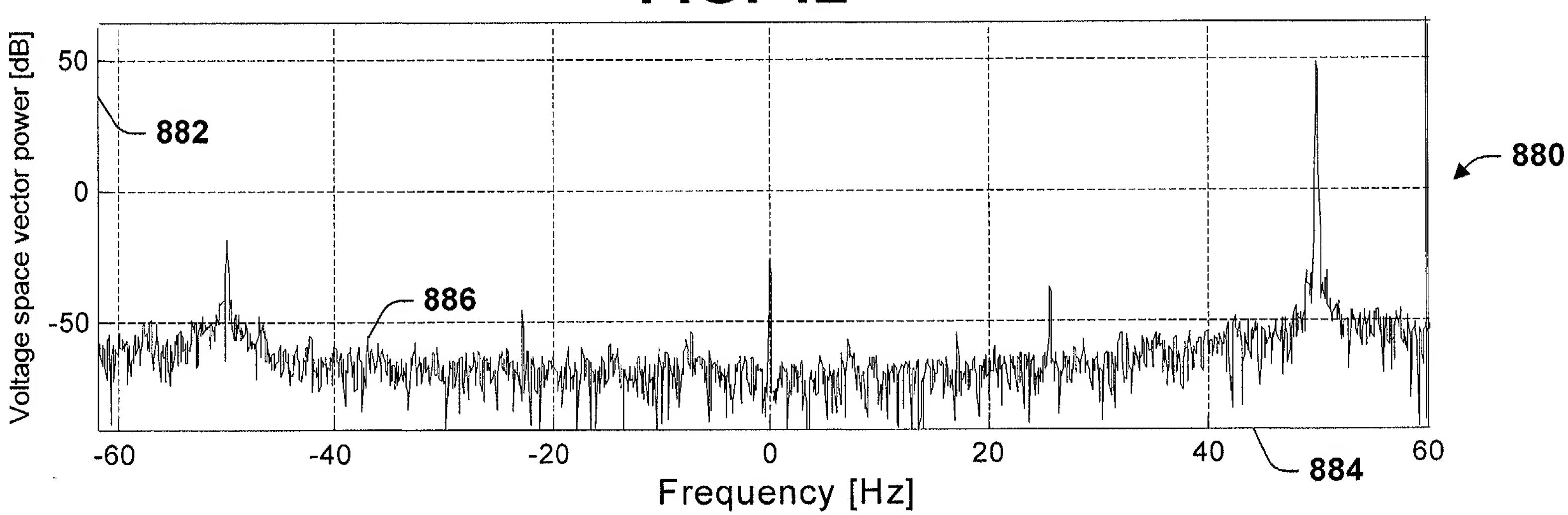
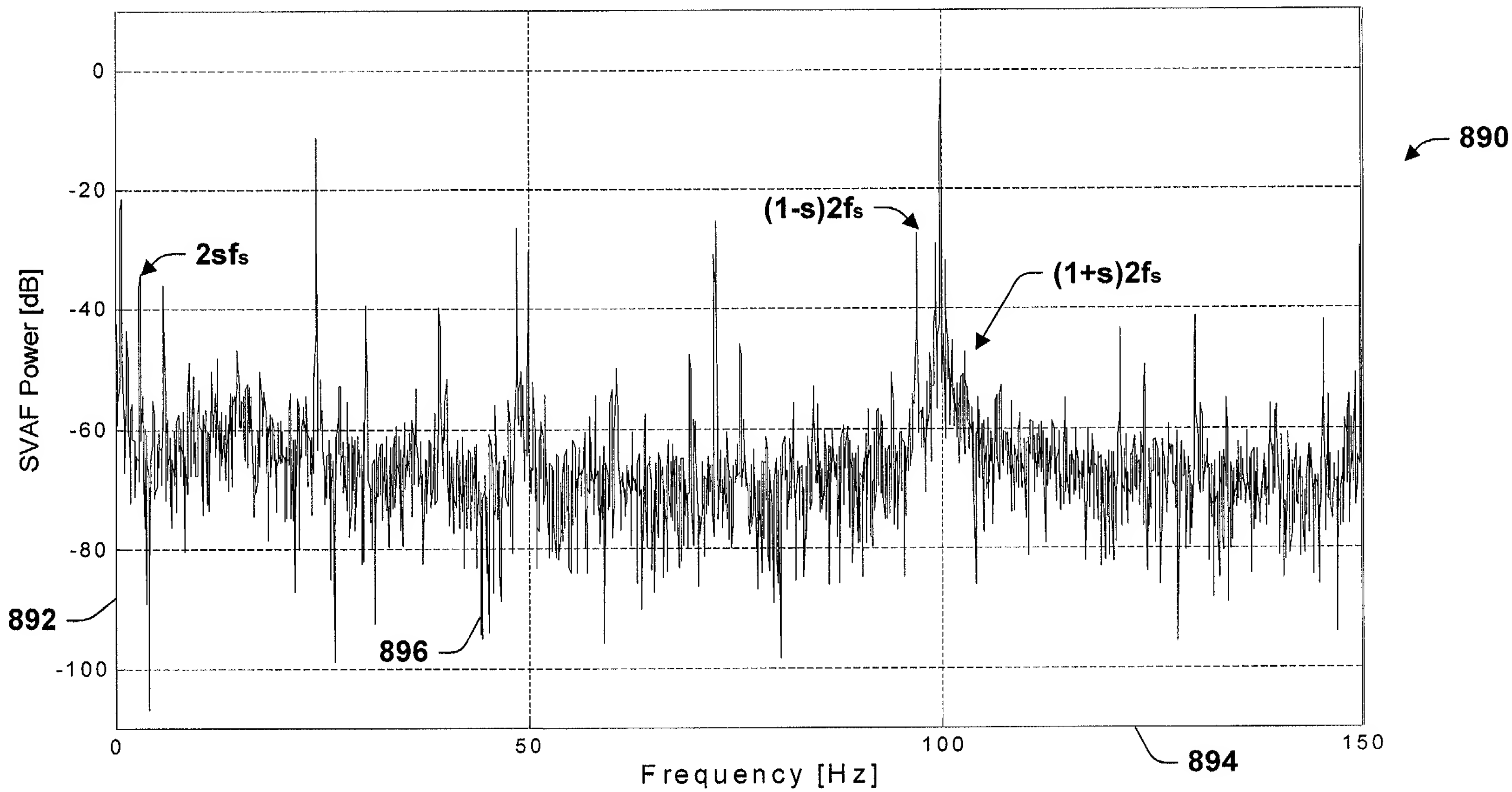

880
882
886
884
Voltage space vector power [dB]
50
0
-50
-60
-40
-20
0
20
40
60
Frequency [Hz]

FIG. 43



890
SVAF Power [dB]
0
-20
-40
-60
-80
-100
892
2sfs
896
(1-s)2fs
(1+s)2fs
0
50
100
150
Frequency [Hz]
894

FIG. 44